APPLEBY'S
HANDBOOK
OF
MACHINERY

SECTION 1.
PRIME MOVERS.

APPLEBY'S

ILLUSTRATED HANDBOOK

OF

LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
1877.

2

APPLEBY'S
ILLUSTRATED HANDBOOK
OF
MACHINERY.

SECTION I.—PRIME MOVERS,

INCLUDING

FIXED, PORTABLE AND MARINE ENGINES, BOILERS,
LOCOMOTIVES, STEAM LAUNCHES, HEATED AIR,
GAS AND WATER ENGINES, TURBINES,
AND WATER WHEELS,

WITH

PRICES, WEIGHTS, MEASUREMENTS, AND SOME DATA ON WORKING EXPENSES AND RESULTS OBTAINED.

BY

C. J. APPLEBY,
(APPLEBY BROS.)
EMERSON STREET, SOUTHWARK, LONDON, S.E.

THIRD EDITION.—REVISED AND ENLARGED

LONDON:
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STAMFORD STREET AND CHARING CROSS.

The Edition of Appleby's Hand-book of Machinery, published in 1869, and several reprints of it having been exhausted, a New Edition (of which this section forms a portion) is now being completed; and for the convenience of those who desire information on specific subjects, but not on all those treated, the book will be divided into eight sections, each of which may be obtained separately as follows:—

Section 1.—PRIME MOVERS.

Steam, Gas and Air Engines, Boilers, Turbines, etc.

Section 2.—HOISTING MACHINERY.

Winding Engines, Hydraulic, Steam and Hand Cranes, Winches and Jacks.

Section 3.—PUMPING MACHINERY.

Pumping Engines, Centrifugal, Steam and Hand Pumps.

Section 4.—MACHINE TOOLS.

For Working Metals, Wood, etc.

Section 5.—CONTRACTORS' PLANT AND RAILWAY MATERIALS,

Including the Machinery and Materials required for the Construction and Equipment of Railways and other Public Works.

Section 6.—COLONIAL AND MANUFACTURING MACHINERY.

For Treating Corn, Coffee, Rice, Sugar, Cotton, and other Products, Oil Mills, Gas Works, etc.

Section 7.—MISCELLANEOUS IRON WORK.

Brass Fittings, Engineer's Tools, and General Stores.

Section 8.—USEFUL TABLES AND MEMORANDA.

For Engineers, Merchants, and Manufacturers, with Prices, Weights, Measurements, Working Results, Cost of Working, etc.

The complete work will form two volumes of about 900 pages, illustrated by nearly 700 Engravings.

The subject matter has been almost entirely rewritten, and the Engravings illustrate for the most part work designed or carried out by the Authors' Firm, and now in successful operation. Details of design, construction, and proportions will be subject to modification from time to time.

The Prices have been corrected up to date, and are based on the present value of metals and labour: they will therefore necessarily be subject to modification if there should be any material change in the value of these items.

Weights and measurements are given approximately, so that the cost of freight, duty, &c., may be roughly estimated; also some data as to the cost of working, the motive power required, and the work performed.

The cost of packing for shipment and delivery to docks varies with the nature of the packing required and the destination, but the average is—

For packing and delivery alongside vessel	in	London	about 3 per cent.
ditto	ditto	Liverpool or Hull ..	about 5 per cent.
ditto	ditto	Cardiff or Glasgow ..	about 7½ per cent.

The details above referred to are in a handy form for reference, and it is hoped they may prove useful alike to Engineers and to users and purchasers of Machinery and Materials connected therewith.

CONTENTS.

SECTION I.

PRIME MOVERS.

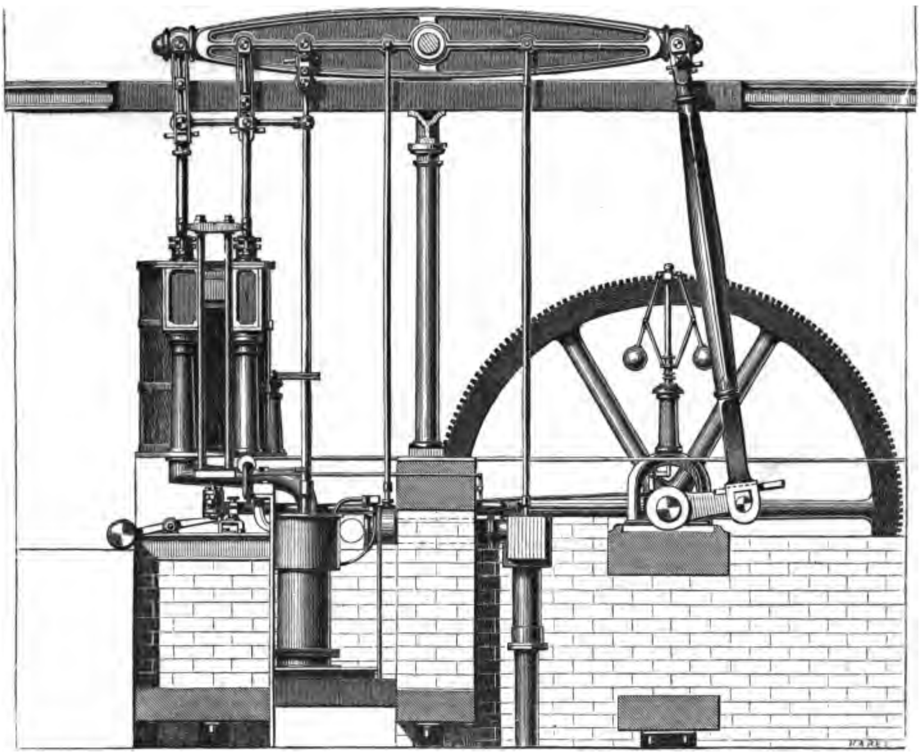


Fig. 1.

COMPOUND BEAM ENGINE, Fig. 1. The experience gained with engines of this type has shown such great economy in consumption of fuel and low cost of maintenance, that they have been used more than any other for driving the machinery of large mills and similar works in this and other countries. The cylinders are high and low pressure, the latter being about four times the capacity of the former; the beam and connecting-rod shown in the engraving are of cast iron, but wrought iron possesses the advantage of greater strength and lightness, and is now generally used for this purpose. The beam and trunnions are carried on two strong girders which are built into the walls of the engine house and supported on cast-iron columns as shown. The piston rods and valve rods are of steel. The valves are driven by a cam, and the engine is complete with condenser, air pump, feed pump, governors, and heavy fly-wheel.

PRICES, &c., OF COMPOUND BEAM ENGINES, Fig. 1.

Nominal horse power of engine ..	30	40	50	60	70	80	90	100
Diameter of high-pressure cylinder	10"	11½"	12½"	14"	15"	16"	17"	18"
Revolutions per minute	30	27	25	22	20	19	18	17
Price of engine	£600	£800	£1000	£1200	£1400	£1600	£1800	£2000
Approximate consumption of coal in lbs. per hour	205	275	340	410	470	500	600	650
Average evaporation of water per hour at 45 lbs.	150	200	250	290	330	380	425	470
Approximate weight in tons ..	20	25	28	35	40	45	50	55
" measurement in c. ft.	450	500	560	700	800	900	1000	1200

Packing for shipment necessarily varies according to circumstances, but will seldom exceed 5 per cent.

THE SINGLE-CYLINDER BEAM ENGINE, Fig. 2, has a massive cast-iron entablature carried on six columns, the lower ends of which rest on a strong cast-iron bedplate. The beam

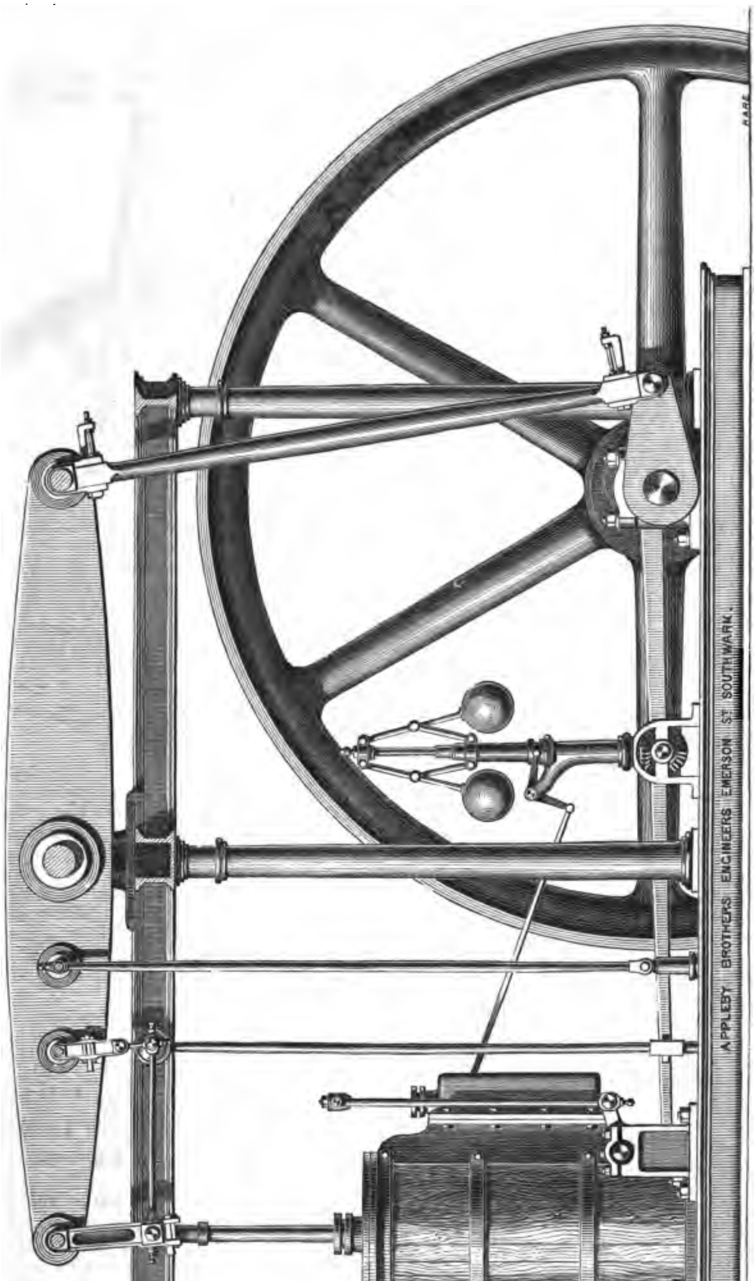


Fig. 2.

is formed of two wrought-iron plates having bosses fastened to them where required; this construction is essentially safe and much lighter than a cast-iron beam, the weight of which frequently presents difficulties in transit. The piston rod is of steel, and is fitted with a metallic piston; the slide valve is driven from a lay shaft, and has a steel rod. The connecting-rod is of wrought iron, with strap ends fitted with gun-metal bearings. The crank shaft has an outer bearing, and carries a heavy fly-wheel; and the engine is complete with governors and all usual accessories. The extra cost for condensers for these engines is about £5 per horse-power.

PRICES, &c., OF SINGLE-CYLINDER BEAM ENGINES, Fig. 2.

Nominal horse power of engines	20	30	40	50
Diameter of cylinder	16″	20″	22″	24″
Stroke of piston	36″	36″	48″	48″
Revolutions per minute	50	50	40	40
Price of engine	£360	£540	£720	£900
Average consumption of coal per hour at 45 lbs. steam pressure	136	205	275	340
„ evaporation of water „ „ „ „ .	100	150	200	250
Approximate weight in tons when packed	15	19	24	27
„ measurement in cubic feet when packed	300	380	480	540

Packing for shipment from 2½ to 5 per cent.

HORIZONTAL HIGH-PRESSURE CONDENSING ENGINE, Fig. 3. The greatly increased cost of fuel, and the growing demand for engines which shall be economical in use as well as moderate in first cost, has led to the use of many engines of the design shown in Fig. 3, in which the details of construction have been most carefully considered; and the high duty which has been obtained from these engines fully demonstrates that commercial economy is to be found in perfection of design and workmanship rather than in a low first cost. The cylinders are made of the best grey iron and are felted and lagged with mahogany, the large sizes being steam jacketted; the valve chest is the full length of the cylinder with double sets of ports and valves, one at each end, which saves the waste caused by filling the long ports with steam at each stroke. The expansion gear is very efficient in its action, and is so arranged that the point of cutting of the steam supply can be varied whilst the engine is running by a hand wheel placed at the back of the slide jacket, an index showing the point of cut-off. The glands are all of great length and bushed with gun metal; the guide blocks are extra long, and work in two pairs of double guide bars, the bottom bars being planed to form oil channels. The centre line of the engine is brought down as near as possible to the level of the bedplate, in order to give increased stability. The length of the connecting-rod is about two and a half times the stroke of the piston, and is forged of scrap iron, the crank pin end being solid, and fitted with gun-metal bearings, adjusting key and lubricator; the crosshead end is also fitted with gun-metal bearings, cotters, and lubricator. The crank shaft and crank are of hammered iron forged in one piece, the shaft being turned and the crank shaped all over. The crank shaft runs in gun-metal bearings of great length, the bearings being made in four peices and adjustable in all directions. The fly-wheel is of ample weight, turned on the face and edges, and securely keyed to the shaft with steel key. The crosshead is of wrought iron, cottered to the steel piston rod. The piston is metallic, fitted with cast-iron rings and steel springs. The air pump is placed on the bed plate directly behind the steam cylinder, the piston or plunger (as the case may be) being coupled to the piston rod, which passes through a gland in the back cover of the steam cylinder. The air-pump chamber is so arranged that it can be used as a jet condenser, or in situations where water is scarce it can be employed in conjunction with an evaporative condenser illustrated in Fig. 13, p. 17; in the latter arrangement the plunger piston is naturally considerably smaller than in the former. The valves of the air pump are india-rubber discs working on gun-metal grids, and having gun-metal guards. The feed pump is on the side of the cylinder opposite to the valve box, and is worked from the crosshead, and is fitted with gun-metal clack boxes and valves. A water heater is frequently placed between the exhaust branch on the cylinder and the condenser, as shown in Fig. 3, and the water, which is drawn from the hot well at a temperature of about 80°, is passed through the water heater and raised to 200° before entering the boiler. The speed of the engine is regulated either by a throttle valve actuated by improved high-speed governors as shown in the engraving, or by a Porter's governor; or, at the cost indicated in the list, the governors can be connected with the valve motion so as to form an automatic cut-off. Engines up to ten horse-power have only one set of steam ports, the shortness of the ports rendering the waste of steam inconsiderable.

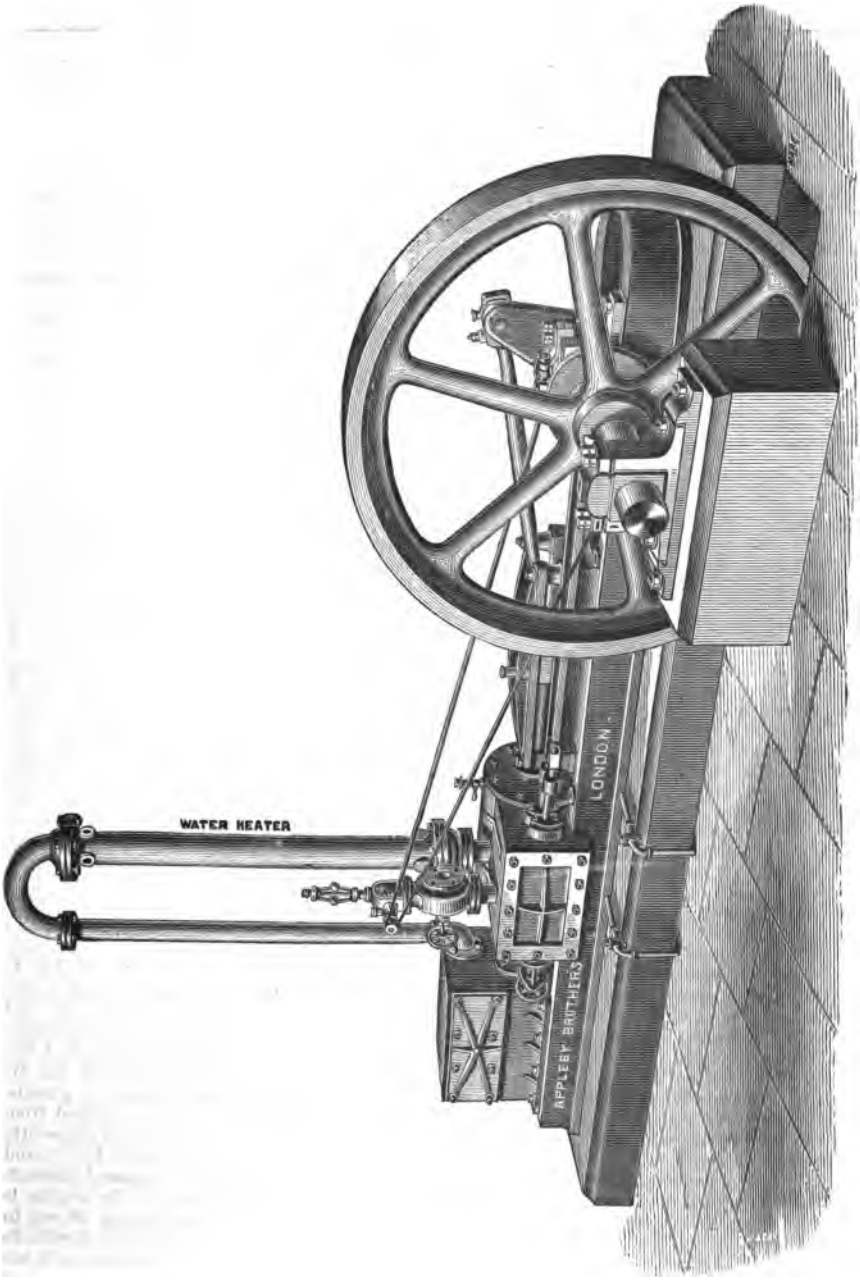


Fig. 3.

PRICES, &c., OF HORIZONTAL CONDENSING ENGINES, Fig. 3.

Nominal horse power of engine ..	6	8	10	12	16	20	25	30	35	40	50
Diameter of cylinders	8″	9″	10″	12″	14½″	16″	18″	20″	21″	22″	24″
Length of stroke	14″	18″	20″	24″	24″	36″	36″	36″	48″	48″	48″
Number of revolutions per minute ..	125	90	85	80	80	50	50	50	40	40	40
Average consumption of coal per hour at 45 lbs. steam pressure ..	42	56	70	84	112	136	172	205	240	275	340
Average evaporation of water per hour at 45 lbs. steam pressure ..	30	40	50	60	80	100	125	150	175	200	250
Price of engine with condenser £	133	163	190	255	303	370	460	530	590	670	820
,, ,, without ,, £	95	125	150	190	243	300	385	450	500	575	715
Price of condensing engine and suitable Cornish boiler .. £	233	278	320	400	470	570	700	800	880	1000	1210
Price of automatic expansion gear extra .. .. .. £	10	12	14	16	18	21	25	30	35	40	50
Approximate weight of condensing engine in cwts.	50	70	95	120	160	250	280	320	380	400	440
Approximate measurement in cub. ft.	100	130	160	250	290	380	450	520	600	650	750

The cost of packing is from 3 to 5 per cent.

HORIZONTAL HIGH-PRESSURE STEAM ENGINE, Fig. 4. This type of engine, having no condenser or expansion gear, is necessarily less economical in consumption of fuel than that last referred to; the results obtained, however, compare favourably with many engines of a more costly character. The centre line of the cylinder is kept as near to the top of the bedplate as possible in order to insure stability, and all the working parts are easy of access; the whole is mounted on a strong cast-iron bedplate, and bolts are provided for securing it to a foundation of stone, brickwork, or timber.

The cylinder is of hard grey metal accurately bored, and has turned flanges and bright covers, metallic piston fitted with wide cast-iron split ring, steel springs and gun-metal tongues; the piston rod is of steel working through a stuffing box of ample length, and is firmly cottered into the crosshead which is got up bright.

The connecting-rod is of hammered scrap iron turned and shaped bright, and both ends are fitted with wrought-iron straps, gun-metal bearings and adjusting keys. The guide blocks are of ample length, and work between two pairs of guide bars, the lower bar of each pair being planed to form an oil trough. The feed pump has gun-metal valves and valve box, and is of ample dimensions for feeding the boiler. The crank shaft is of hammered scrap iron turned bright, and carries a heavy cast-iron fly-wheel; it is also left long enough to take the strap pulleys or gear required for transmitting the power of the engine. The disc plate is of cast iron, turned on the face and edges, and is firmly keyed to this shaft by a sunk steel key. The slide valve is planed and scraped on the face, and is fitted with a steel spindle and driven by a cast-iron eccentric with gun-metal strap and wrought-iron rod. The speed of the engine is regulated by a throttle valve and low-speed governors, but a Porter's or other high-speed governor is supplied at a slight extra cost.

These engines may be fitted with link reversing motions or with expansion gear adjustable by a hand wheel at the back of the valve chamber whilst the engine is running, or by an eccentric which can be shifted on the crank shaft, or automatically from the governors. The extra cost varies from £8 to £50, according to the size of the engine and the kind of gear adopted.

The boilers usually employed are of the Cornish type, the smaller sizes with one, and the larger with two tubes; in all cases they are of ample size and strength, made of the best materials and workmanship, and are furnished with all mountings necessary for safety as well as for efficient and economical working, including glass water-gauge, gauge cocks, patent steam-pressure gauge, double safety valve, fusible plug in the crown of the flue, blow-off cock, &c., &c. Special attention is directed to the water heaters described at p. 66, and to the remarks on the great saving in fuel which is effected by heating the feed water before it passes into the boiler.

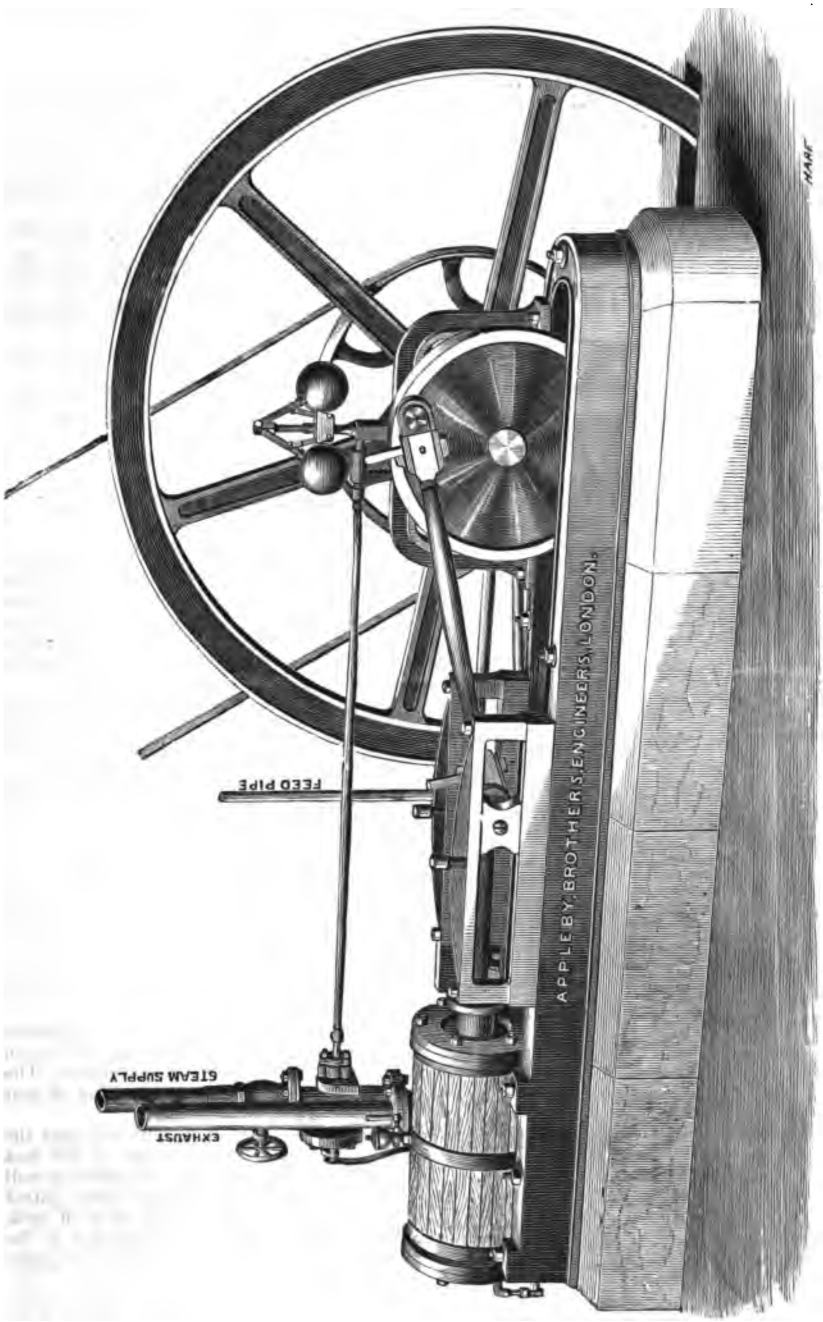

APPLEBY, BROTHERS, ENGINEERS, LONDON.
FEED PIPE
STEAM SUPPLY
EXHAUST

Fig. 4.

PRICES, &c., OF SINGLE-CYLINDER HORIZONTAL HIGH-PRESSURE STEAM ENGINES, Fig. 4.

Nominal horse power of engines ..	4	6	8	10	12	16	20	25	30	40	50
Diameter of cylinder	6½"	8"	9"	10"	12"	14½"	16"	18"	20"	22"	24"
Length of stroke	12"	14"	18"	20"	24"	24"	36"	36"	36"	48"	48"
Number of revolutions per minute ..	150	125	90	85	80	80	50	50	50	40	40
Price of engine .. .. £	57	82	106	126	150	200	242	333	388	500	620
Price of suitable Cornish boiler and fittings .. .. .. £	73	84	108	120	144	180	230	275	337	365	460
Average consumption of coal per hour at 45 lbs.	32	42	56	70	84	112	136	172	205	275	340
Average evaporation of water per hour at 45 lbs.	22	30	40	50	60	80	100	125	150	200	250
Approximate weight of engine, packed, in cwts.	18	45	48	50	70	100	115	130	160	230	280
Approximate measurement of engine in cubic ft.	40	83	90	95	145	215	245	260	280	400	480
Approximate weight of Cornish boiler and fittings in cwts.	26	45	50	57	70	115	120	140	230	240	280

For engravings, description, and prices of boilers, see pp. 54 to 64.
The cost of packing necessarily varies with circumstances, but will seldom exceed 5 per cent.

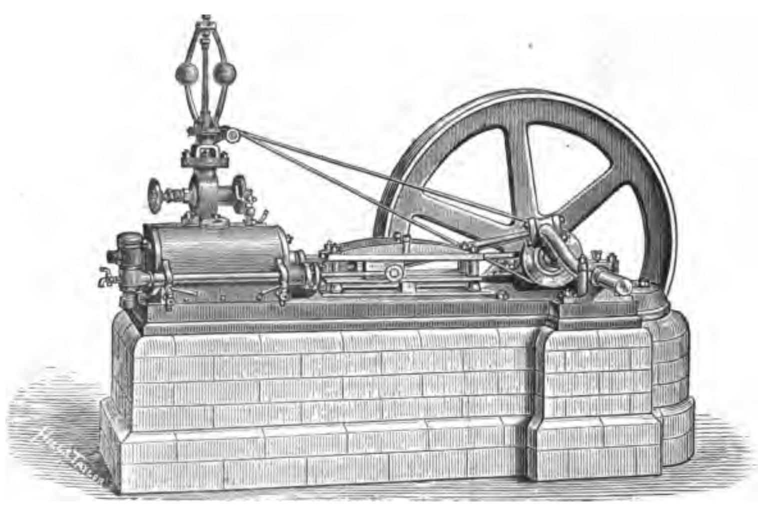


Fig. 5.

HIGH-PRESSURE HORIZONTAL STEAM ENGINE, Fig. 5, from 1 to 6 horse-power, with wrought-iron bent crank, high-speed governors, feed pump, and fly-wheel. These engines are well designed and carefully fitted in the working parts, but superfluous finish is avoided in order to reduce the cost as far as practicable. Engines of this type are much used for numerous purposes where a fixed engine of moderate power is required in small factories, for driving printing presses, pumps for raising water or for working hydraulic presses, and for many other operations in which steam power will be far more economical than manual labour.

The cost of steam pipes between engine and boiler is not included in the subjoined prices.

PRICES, &c., OF SMALL HORIZONTAL STEAM ENGINES, Fig. 5.

Nominal horse power of engine ..	1	2	2½	3	4	6
Diameter of cylinder	3½"	4½"	5⅛"	5½"	6½"	8"
Length of stroke	7"	7"	9"	10"	11"	15"
Revolutions per minute	200	200	160	150	135	100
Price of engine only	£19 15	£24 0	£26 10	£32 10	£48 0	£72 0
Price of engine and vertical boiler	£53 0	£63 0	£68 0	£83 0	£111 0	£160 0
Approximate weight in cwts. ..	5	6	7½	8	10	12
" shipping measurement in cubic ft.	10	12	15	16	20	25

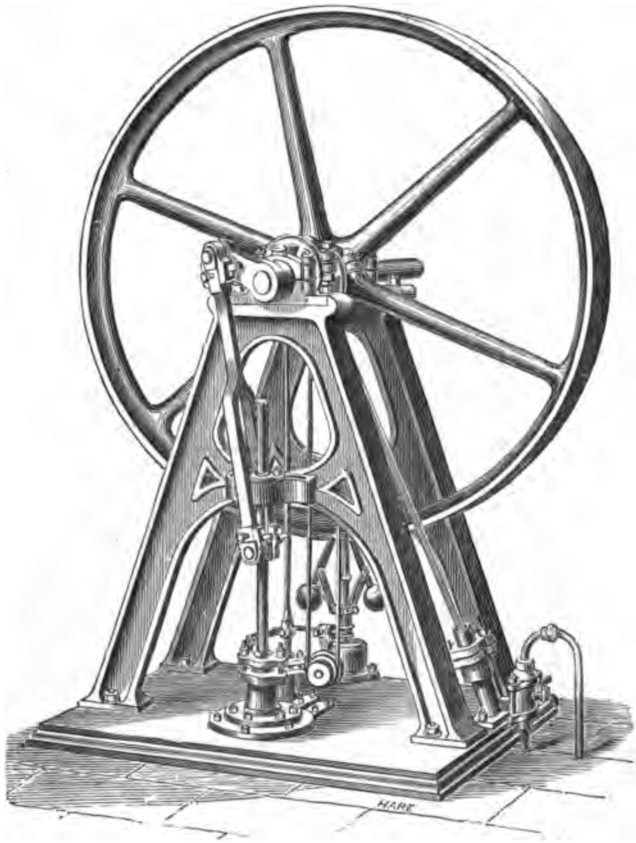


Fig. 6.

THE VERTICAL HIGH-PRESSURE STEAM ENGINE, Fig. 6, occupies less space than a horizontal engine, but at a sacrifice of a certain degree of stability.

The frames and all the working parts of the engine are mounted on a strong cast-iron bedplate, and the whole is easily erected on a brick or timber foundation; in fact in some cases they are simply bolted to the floor of a warehouse, and set to work without any other foundation. The cylinder is of hard grey metal, and is fixed to the bedplate by the top flange in order to keep the centre of the crank shaft as low as possible, and fitted with metallic piston with rings and springs. The piston rod is of steel, and is carried forward beyond the crosshead to

form a guide as shown. The connecting-rod is of wrought iron, forked and fitted at each end with gun-metal bearings. The crank and crank shaft are of wrought iron, the latter running in plummer blocks, fitted with adjustable gun-metal bearings. A heavy cast-iron fly-wheel is keyed on this shaft, and the end is usually (but not necessarily) carried in a wall box. The slide valve is driven by an eccentric with gunmetal strap, the same eccentric also working the feed pump. The engine is fitted with slow-speed governors, but high-speed governors can be substituted if desired, and link reversing motion can be fitted to the engine at a slight additional cost.

The prices, &c., of these engines and suitable boilers are the same as the horizontal engines, Fig. 4.

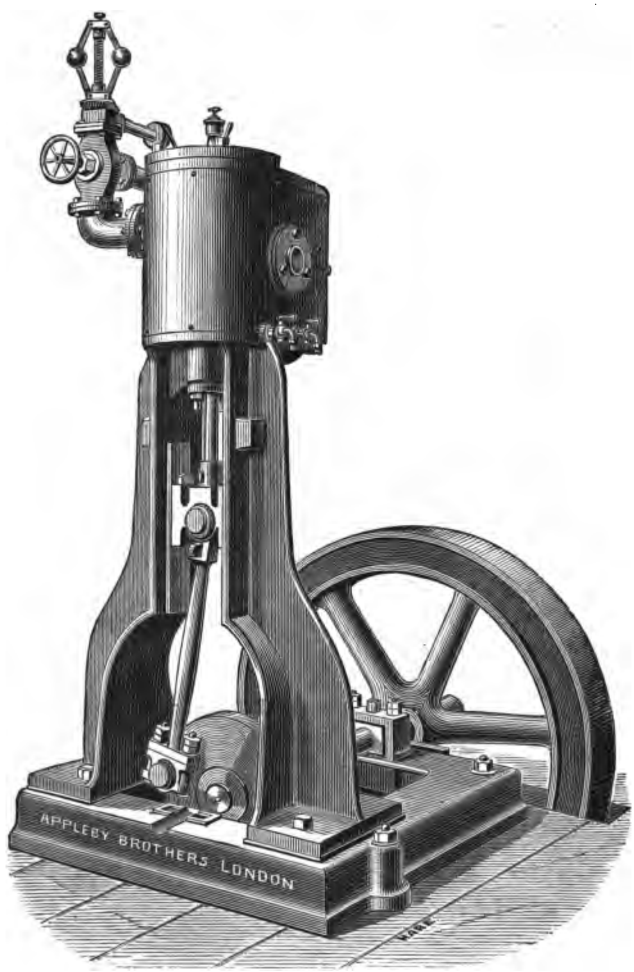


Fig. 7.

THE SMALL VERTICAL STEAM ENGINE, Fig. 7, with inverted cylinder, from a photograph of a 4-horse engine, illustrates a construction which is very compact and steady in working. The cylinder is of hard cast iron fitted wiih metallic piston with rings and springs. The piston rod is of steel cottered into cast iron adjustable guide block working in bored guides. The connecting-rod is of wrought iron fitted with gun-metal bearings. The wrought-iron crank pin is fixed in a cast-iron balanced disc plate, and the crank shaft is of wrought iron,

running in gun-metal bearings, and carrying a heavy fly-wheel. The engine is complete with feed pump and high-speed governors.

PRICES, &c., OF SMALL VERTICAL ENGINES, Fig. 7.

Nominal horse power	1½	2	3	4	6	8	10	12
Diameter of cylinder	3½"	4½"	5¾"	6¾"	8"	9½"	10½"	11½"
Length of stroke	6"	7"	8½"	10"	14"	16"	18"	20"
Number of revolutions per minute	250	200	180	150	110	95	85	80
Price for engine with feed pump	£38	£42	£52	£60	£90	£124	£150	£175
Approximate weight in cwts. ..	5¼	6¼	11	17	28	39	53	65
" shipping measurement in cubic ft.	11	13	22	34	56	78	106	130

For boilers see pages 54 to 64. Packing for shipment about 5 per cent. extra.

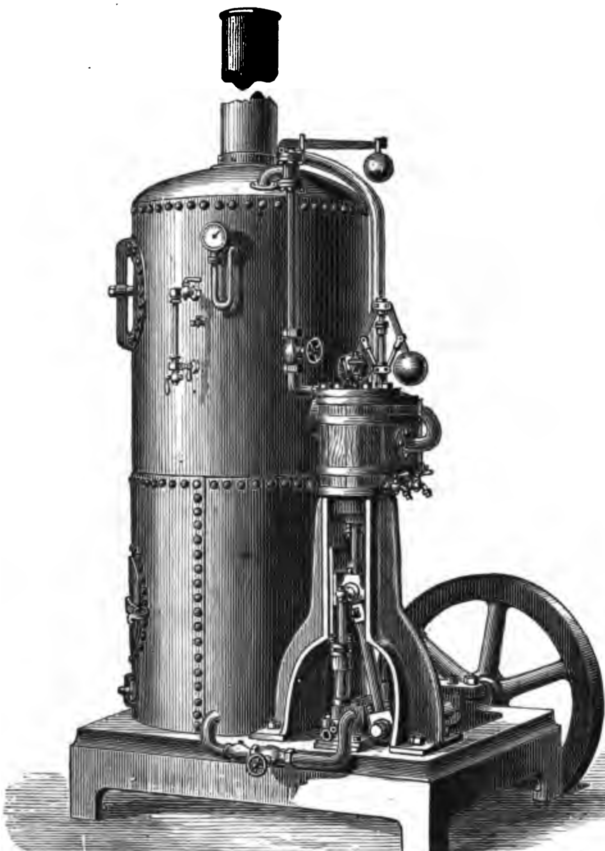


Fig. 8.

SMALL INVERTED VERTICAL ENGINE AND BOILER ON FOUNDATION PLATE, Fig. 8. The engine is similar to that shown in Fig. 7, excepting that it has a slow-speed governor, and is mounted with its boiler on a strong cast-iron bedplate. This arrangement is compact, and the weight being distributed over a considerable area, no special foundation is required.

70

It can be fitted with link reversing motion at a slightly increased cost, and with governors similar to those shown in Fig. 7. The boiler has the usual mountings, including safety valve, steam-pressure gauge, glass water gauge, &c., and the whole is complete ready for work.

Prices, &c., of Small Inverted Vertical Engines and Vertical Boilers, Fig. 8.

Nominal horse power	1½	2	3	4	6	8	10	12
Diameter of cylinder	3½"	4½"	5¾"	6¾"	8"	9½"	10½"	11½"
Length of stroke	6"	7"	8½"	10"	14"	16"	18"	20"
Number of revolutions per minute	250	200	180	150	110	95	85	80
Price complete, as shown	£78	£91	£120	£143	£180	£228	£286	£310
Approximate weight in cwts. ..	15	25	36	50	67	80	90	100
" shipping measurement in cubic ft.	30	50	72	100	130	160	180	200

The cost of packing is about 5 per cent.

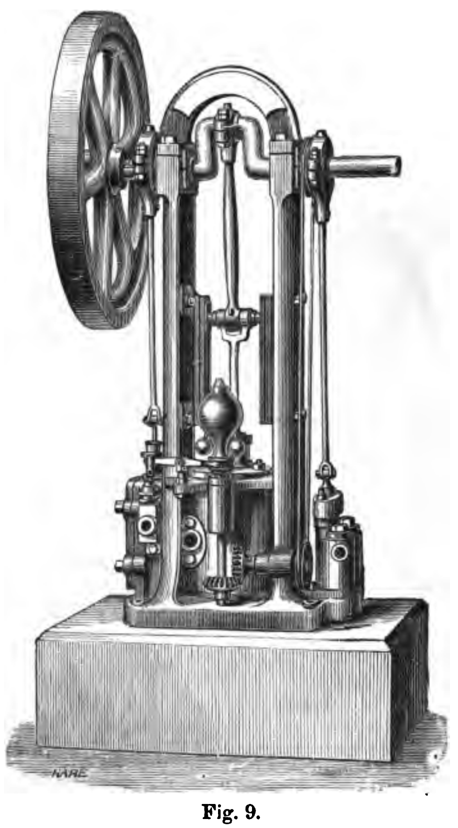


Fig. 9.

SMALL FIXED VERTICAL STEAM ENGINE, Fig. 9, has the cylinder below and the crank shaft above, the whole being mounted on a strong cast-iron baseplate suitable for bolting to masonry or timber. The cylinder is of hard grey cast iron fitted with metallic piston with rings and springs. The connecting-rod is of wrought iron with gun-metal head, and the guide block works between adjustable V guides. The engine is fitted with a simple reversing disc by which it can be easily made to run in either direction, and is complete with wrought-iron bent crank shaft long enough to take power from either end, heavy fly-wheel, governors, and gun-metal feed pump. The engine and boiler, Fig. 10, stand on a hollow cast-iron base-

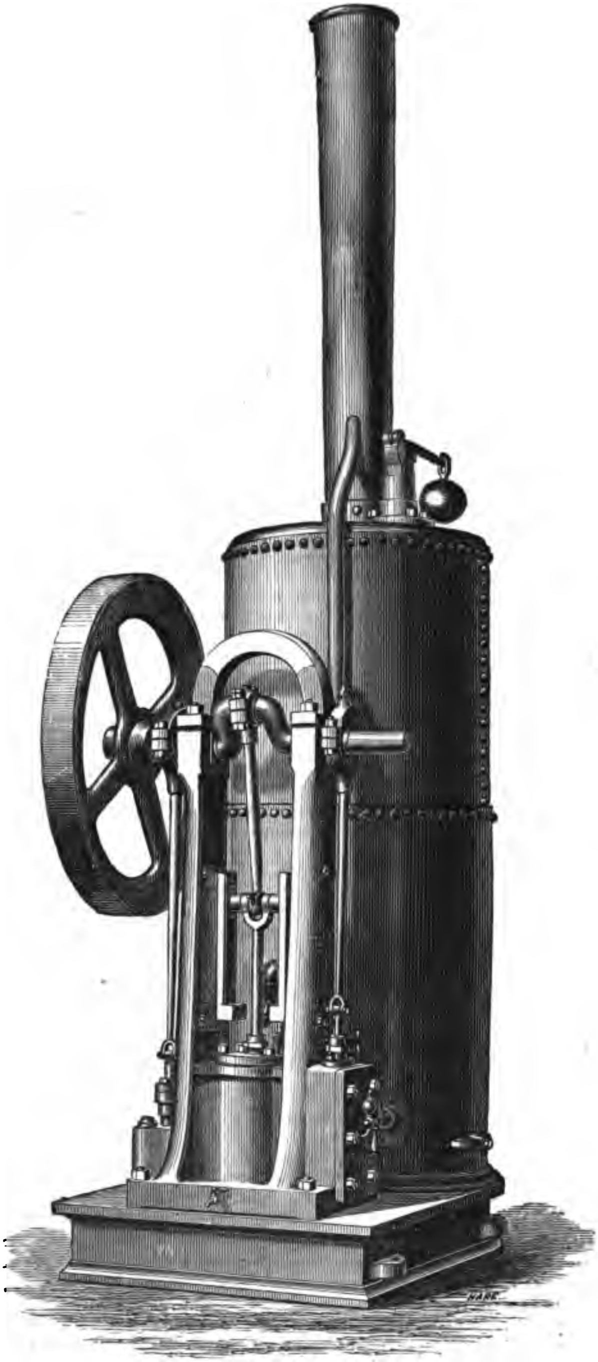


Fig. 10.

plate which forms a feed-water tank. The boiler is of ample proportions, and is fitted with all steam and furnace mountings necessary for working with efficiency, economy, and safety.

PRICES OF SMALL VERTICAL ENGINES AND BOILERS, Figs. 9 and 10.

Nominal horse power	1	2	3	4	5	6
Diameter of cylinder	4″	5″	6″	7″	7¾″	8½″
Length of stroke	6″	8″	9″	10″	12″	12″
Number of revolutions per minute	230	180	150	150	140	140
Price of engine only	£33	£41	£52	£66	£74	£82
" " and boiler	£69	£90	£115	£138	£164	£186
Approximate weight of engine in cwts.	8	15	21	26	32	35
" " " with boiler (Fig. 10)	18	30	42	52	65	70
" measurement of engine in cubic ft.	16	30	42	52	64	70
" " " with boiler ..	38	66	85	105	136	150

The cost of packing for shipment is usually 5 per cent.

THE DOUBLE-CYLINDER VERTICAL ENGINE AND BOILER ON BASEPLATE, Fig. 11, is adapted for use in situations where space and cost of erection are important considerations. The cylinders are inverted and are carried on two strong cast-iron A-shaped frames; the slide, valves and boxes being on the outside are readily accessible. The wrought-iron crank shaft is fitted with three wide adjustable gun-metal bearings, and long enough to take a broad strap pulley outside the fly-wheel and one at the opposite end if desired. A cast-iron cross stretcher connects the two A-frames about midway between the cylinders and the crank shaft, and carries a pair of cast-iron feed pumps with gun-metal boxes and valves; the plungers working in these pumps are a continuation of the piston rods beyond the crosshead, and form the piston-rod guides. The connecting-rods are of wrought iron forked to miss the pumps, and fitted at each end with gun-metal bearings, wrought-iron straps and cotters. The governors are outside one of the frames directly over the crank shaft, and are driven by a strap and conical speed pulleys. The boiler is vertical with two or more cross tubes in the fire box, and fitted with all the usual mountings including safety valves, pressure gauge, glass water gauge, gauge cocks, manhole, mudholes, &c. The engine and boiler are fixed on a cast-iron baseplate, and the whole may be bolted to strong timbers or put down on a bed of masonry or concrete. These engines are sometimes mounted on a cast-iron feed-water tank, especially when a timber foundation is used; the extra cost is about 7½ per cent. High-speed governors, or link reversing motion if desired, can be fitted. The cost of the latter will be found in the annexed list.

PRICES, &c., OF DOUBLE-CYLINDER VERTICAL ENGINES AND BOILERS, Fig. 11.

Nominal horse power	8	10	12	16
Diameter of each cylinder	6½″	7″	8″	9″
Length of stroke	12″	14″	15″	15″
Number of revolutions per minute	125	105	100	100
Price of engine and boiler as shown	£270	£315	£385	£470
Price extra for link reversing motion	£18	£20	£22	£24
Approximate weight, packed, in cwts.	80	90	100	120
" measurement in cubic ft.	300	380	460	550

Packing for shipment costs from 3 to 5 per cent.

VERTICAL STEAM ENGINE ON BOILER, Fig. 12. The steam cylinder is bolted to the boiler, and no foundation or bedplate is required excepting the circular feed-water tank (of about the same diameter as the boiler) on which the whole is mounted; it may therefore be placed on a brick or timber floor, and immediately set to work. A very large number of engines of this type have been in hard and constant work for many years past (amongst others one was used by the Authors in their own works), and they have given most satisfactory results both as to stability and durability. The cylinders are of best grey cast iron, firmly bolted to the lower part of the boiler, accurately bored, and fitted with metallic pistons and steel piston rods. The end of the piston rod is continued beyond the crosshead, and works in a guide bracket bolted to the boiler. The connecting-rod is of wrought iron forked to miss the guide bracket, and fitted at each end with gun-metal bearings, wrought-iron straps and cotters. The wrought-iron crank pin is case-hardened, and firmly fixed in a cast-iron balanced crank plate which is turned bright all over. The wrought-iron crank shaft runs in gun-metal bearings carried on the top of the boiler, and is left long enough to take a strap pulley beyond the fly-wheel; the

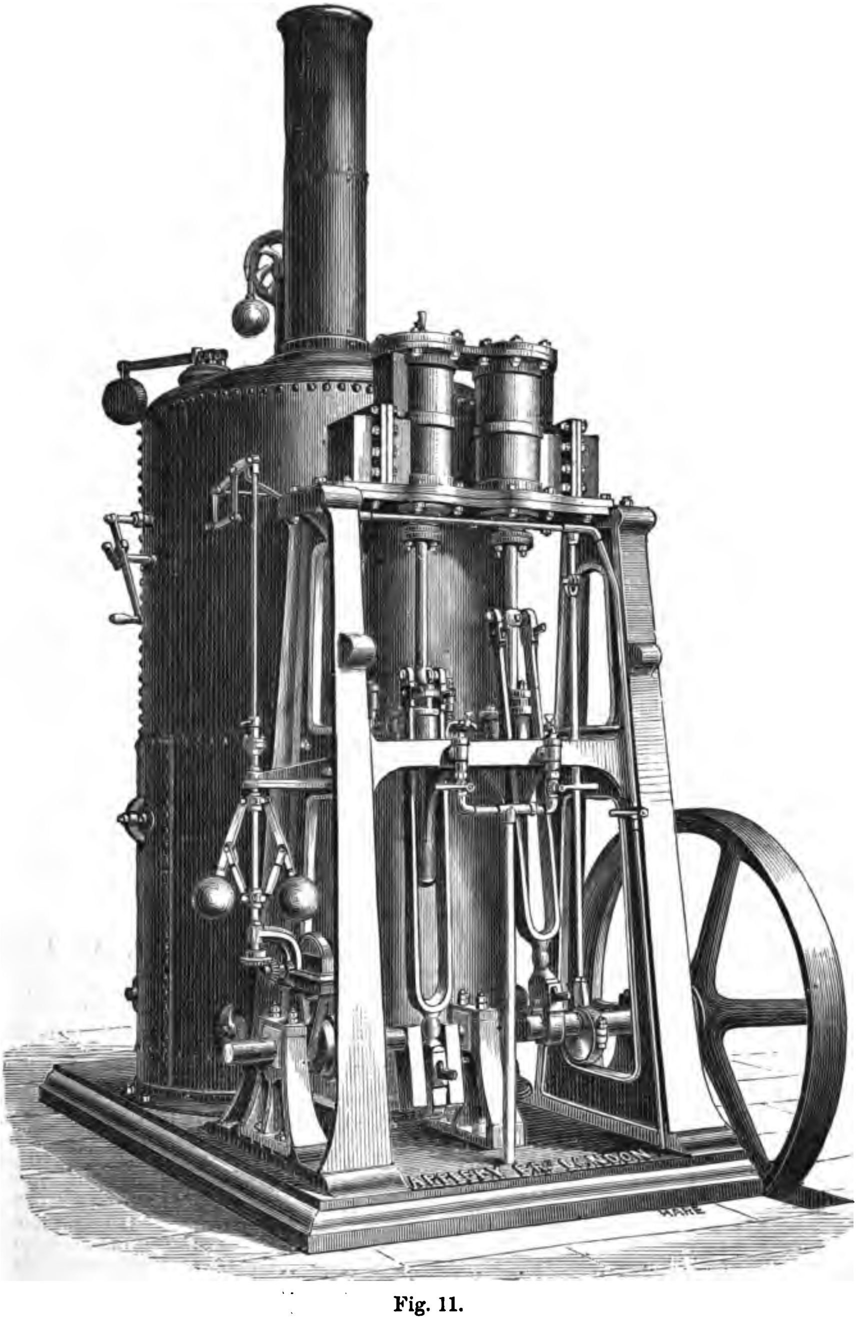


Fig. 11.

Fig. 12.

fly-wheel is also turned on the face and may be used as a strap pulley if desired. A feed pump is provided, worked from an eccentric on the crank shaft and fitted with gun-metal valves and boxes, and the engine is complete with governors and throttle valve. The chimney is placed out of the centre to leave room for the engine work, and the boiler is fitted with all mountings necessary for its safe and economical working, including safety valve, pressure gauge, glass water gauge, gauge cocks, fusible plug, &c.

When the engine is required for constant work, the boiler and cylinder should be felted and lagged as shown, and prices are given both with and without lagging.

PRICES, &c., OF VERTICAL STEAM ENGINES ON BOILERS, Fig. 12.

Nominal horse power	3	4	6
Diameter of cylinder	5½"	6½"	7¼"
Length of stroke	9"	10"	14"
Number of revolutions per minute	160	150	105
Price complete, with lagging as shown	£96	£132	£180
Price without lagging	£84	£120	£165
Approximate weight in cwts.	33	45	60
„ measurement in cubic ft.	70	90	120

Cost of packing for shipment from 3 to 5 per cent.

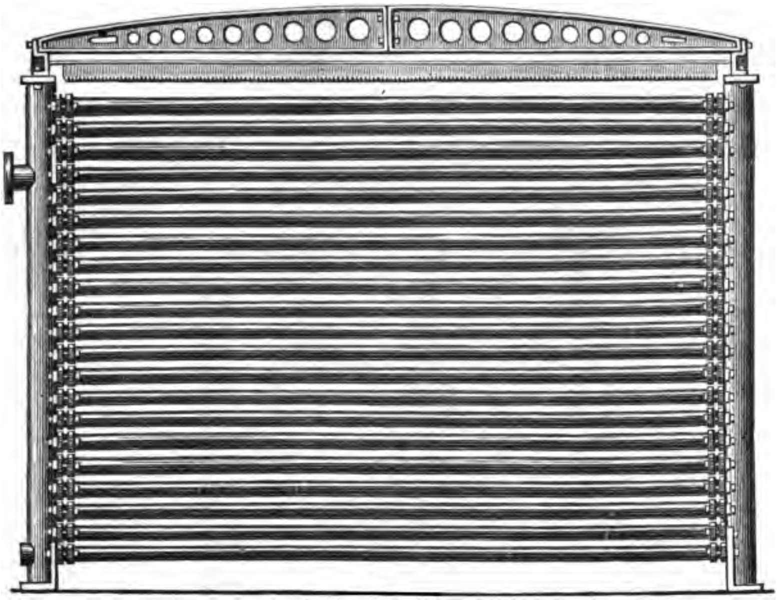


Fig. 13.

PATENT EVAPORATIVE SURFACE CONDENSER, Fig. 13. This system is invaluable where the supply of water is limited or costly, a good vacuum being maintained with a consumption of water which is altogether unattainable by any other method of condensation. These conditions exist in London and in many large towns, as well as in all countries where water suitable for feeding boilers is scarce, and fuel expensive. The Authors have carefully tested the apparatus at their own works in London, where they have applied it to a single-cylinder horizontal engine; the condenser has now been at work for some time, and the saving in fuel has been at least 20 per cent. This is sufficiently important in itself; but there is the further great advantage that the scale on the boiler, which formerly caused great inconvenience, has now almost entirely disappeared. The construction is remarkably simple, and the absence of any element liable to derangement renders this system of condensation specially valuable in isolated places in connection with steam engines, vacuum pans, &c.

The condenser consists of a number of copper tubes with cast-iron boxes at each end, and a copper trough with serrated edges at the top, as shown in the engraving. The steam to be condensed is admitted into the cast-iron boxes, and spreading through the copper pipes the condensation is effected by a shower of water flowing over the serrated edges of the copper trough and trickling down over the exterior of the pipes. Thus the condensing water is converted into steam, and absorbs not only its proportion of sensible heat, but also some latent heat, producing at least five times greater effect than is obtained by injection. The water lost by evaporation outside the tubes is only equal to that produced by the condensation of the steam within them, and the consumption of water is but little more than is required for an ordinary high-pressure engine of equal power, because the condensed water is returned to the boiler in a heated state, and so is used again. The apparatus may be at a considerable distance from the engine, and the more exposed the situation the better the result obtained, the atmosphere assisting to some extent to maintain the vacuum.

The cost of the condenser is about £7 per nominal horse-power of the engine, but the total cost will necessarily be affected by the distance between the engine and condenser, the facilities for obtaining a supply of water, and other circumstances. The data required for estimating the size and cost of the condenser required is furnished by an indicator diagram, or if that cannot be obtained it will be necessary to give—

The temperature of steam as it leaves the cylinder, or the initial pressure and point of cut off.

The diameter, length of stroke, and number of revolutions made by the engine.

The position of the condenser relatively with the engines.

These condensers may be applied to almost any existing high-pressure engine, or a number of engines may be connected to one set of condensers: in the latter case a group of cast-iron

pipes fixed vertically give a very excellent result, but the quantity of condensing water required is larger than if thin copper pipes of small diameter are used. A further and very marked economy in the consumption of fuel is obtained by using a water heater (see Fig. 55, p. 66), which is fixed between the engine and the condenser.

SAULT'S SYPHON CONDENSER, Fig. 14. The advantages claimed are, that no air-pump being required there is an economy of 10 per cent. in the fuel consumed, as compared with an ordinary jet condenser with its air-pump, &c., or of 25 per cent. when it is applied to a high-pressure non-condensing engine.

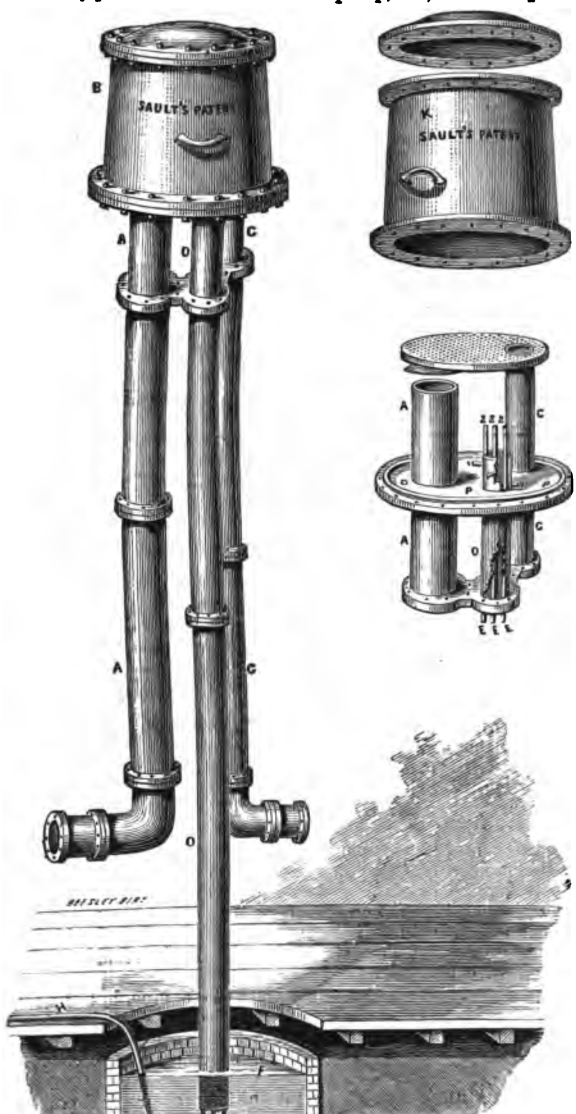


Fig. 14.

The cost is about 2*s.* 6*d.* per circular inch in area of the steam cylinder, therefore the cost of a Sault's Condenser for an engine with a steam cylinder 16 inches diameter is £32; this compares favourably with the cost of nay of the condensers in general use.

As there are no valves or moving parts there is no wear and tear, and the arrangement is so simple that it is easily understood and worked by any ordinary engine-driver.

Another advantage is, that one of these condensers can usually be fixed without interference with the ordinary working hours of a factory, the connection with the engine being made in one night.

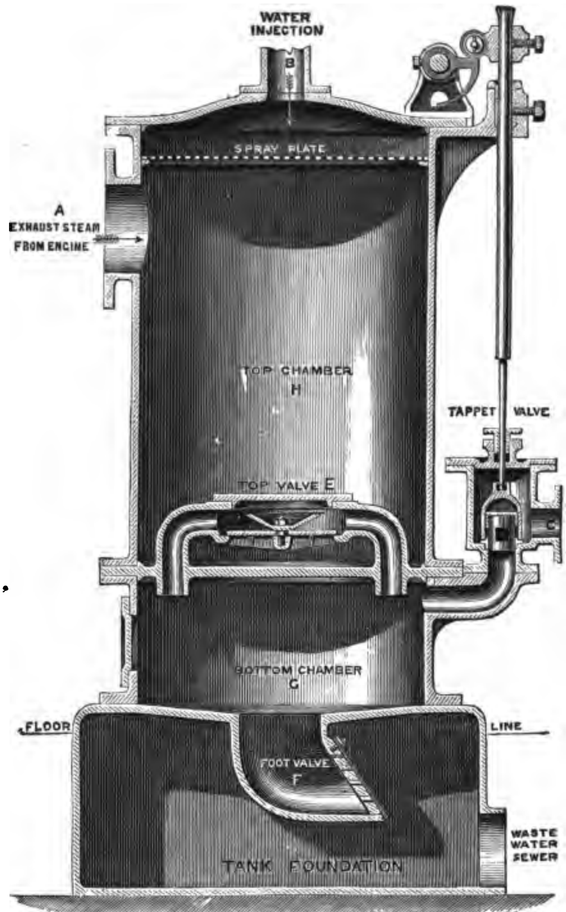
Where more power is required the increase in useful effect obtained from a high-pressure non-condensing engine, after this apparatus has been fitted, will frequently provide the additional power without putting down a new engine, and without an increase in the consumption of fuel.

A small pump is required to lift the condensing water, but the power to drive this is less than 10 per cent. of that required to work an air pump; and although at first starting the pump has to lift the water to the condenser B, after a vacuum is created it only has to lift it (the water) about 5 feet, the vacuum drawing it the rest of the way. The condenser is fixed about 34 feet above the water in the overflow or hot well.

This condenser is suitable for application to sugar pans, oil stills, or any apparatus requiring a vacuum. The exhaust from the engine or vacuum pan is conducted by the pipe A to the lower part of the condenser B. The injection from the pump or other supply enters through the pipe C, and is caused by a perforated diaphragm to descend on the exhaust in the form of rain; as the steam is condensed, its water and the injection water fall by the small pipes E E E into the hot well F. The feed water for boiler can be taken from this hot well at a temperature of 80 to 100 degrees Fahrenheit.

THE MACARTER CONDENSER, Fig. 15, has now been thoroughly tested, and proved to be a valuable adjunct to the high-pressure steam engine. It can be readily fixed to any existing engine, and the results obtained show considerable increase in power, without a corresponding increase in the consumption of fuel.

No air pump is required, and indeed when it has replaced ordinary condensers with air pumps, it has effected considerable saving of coal. The action is very simple. The condenser consists of two chambers, one over the other: the exhaust steam from the engine is admitted to the upper chamber, and is there condensed by contact with the injection water, which is brought in at the top, and made to fall in a perforated plate, which produces a rain-like spray. The condensed steam and injection water is drained away by alternately creating and destroying a vacuum in the lower chamber. This is accomplished by first opening a valve, and admitting a small quantity of steam at a very low pressure (1 or 2 lbs. per square inch), and then opening a valve to admit cold water: these two valves are actuated by tappets geared up to a shaft to produce seven strokes per minute. A remarkably steady vacuum of about 28 in. is obtained with about half the water used in the ordinary jet condenser, and the condenser will draw its own water from any depth up to 27 ft. Salt, muddy, or even sandy water may be used, if pure water cannot be obtained. The cost of the condenser for engines up to 25 horse-power, is £5 for each inch in the diameter of cylinder, and for larger sizes £4 10*s.*; but they are not made for smaller than 13-in. cylinders. One of these condensers is stated to have effected a saving in cost of fuel of 35 per cent.; whilst at another mill the owners certify a saving of about 30 per cent.



SECTIONAL ELEVATION.
Fig. 15.

KORTING'S JET CONDENSER, like the foregoing, requires no air pump, and can easily be fixed to an existing engine. No valves or tappets are required to get rid of the condensed steam, and the engine driver has only to turn on and off the water and air valves when starting and stopping the engines. Thirty-five sizes are made, and the system is equally applicable to large or small engines. The price varies from £7 to £200, the largest size being suitable for engines of 400 horse-power.

HOLMAN'S CONDENSERS AND SAXBY CONDENSERS are specially designed for use in conjunction with direct-acting steam pumps or other pumping engines, but there are cases where they may be advantageously applied to high-pressure non-condensing engines,

They both effect a large saving in the consumption of fuel, and get rid of the exhaust steam, which is often a serious nuisance in mines and underground workings.

PRICES OF HOLMAN'S PATENT CONDENSERS.

Diameter of steam cylinders	7"	12"	14"	21"	32"
Diameter of pump	3"	4"	6"	8"	10"
Price	£6 10	£9	£12	£18 10	£30

PRICES OF SAXBY'S PATENT CONDENSERS.

Diameter of steam cylinders ..	8"	10"	12"	14"	16"	18"	20"	24"
Prices	£10	£15	£20	£25	£30	£35	£45	£55
Prices of two-way valve for ditto	£2	£3	£4	£5	£6	£7	£8	£9

LOCOMOTIVES.—Probably no subject in connection with railway practice has been so much discussed, and certainly on none has there been so wide a divergence of opinion, as on that of gauge. The question has, however, long ago passed from one of theory to that of practice, and the results obtained from the narrow-gauge lines, mostly of one metre, or of 3 ft. 6 in. gauge, which have been made in India, the United States, South America, many of our own Colonies, and in almost every country in Europe, have at least shown that under some conditions these gauges can be used with marked advantage. Mr. Fowler's investigations prior to his very able report on the Indian Railways, led him to recommend a 3 ft. 6 in. gauge, mainly because that appeared to him to be the narrowest gauge for which really well-designed engines and rolling stock could be built, and that relatively with the dead weight. a larger carrying capacity was attained than with any other narrow gauge. He has since then adopted this (3 ft. 6 in.) as the gauge of the Soudan Railway, the whole of the materials for which are supplied by the Authors, and some illustrations are given of the rolling stock, &c., made from Mr. Fowler's designs.

Narrow-gauge lines from 2 ft. 8 in. to 3 ft. 6 in. have also been used by contractors; and the low total cost of road, locomotives and rolling stock, as well as the facilities which the narrow gauge affords for running to tip on a narrow bank, or for use on staging, &c., in the construction of harbours, breakwaters, and similar works, have proved most advantageous wherever it has been adopted. The illustrations and descriptions are only intended as an indication of the types of engines which the Authors have been called upon principally to supply, and which can usually be sent away at a short notice.

SIX-WHEELED TANK LOCOMOTIVE, Fig. 16. Engines of this type are made of the several powers enumerated in the subjoined list, and for almost any gauge, without material alteration in design or arrangement; but that selected for illustration is for 4 ft. 8½ in. gauge, the cylinders are 14 in. diameter by 22 in. stroke, and it will haul a load of 500 tons on the level. The saddle tank contains 1000 gallons of water, and the coal bunk carries one ton, sufficient for a run of 35 miles; the weight empty is 24 tons, and when in running order, the engine weighs about 32 tons.

The barrel of the boiler is 9 feet long by 3 ft. 5 in. diameter, and has 140 solid drawn brass tubes 1⅝ in. diameter; the shell is made of best plates, ⅜ in. thick, and the outer fire-box plates are 7/16 in.; the boiler is stayed for a working pressure of 120 lbs., and is tested by hydraulic pressure to 200 lbs. per square inch. The internal fire box is of best hammered copper, ⅜ in. thick, excepting the tube plate, which is 11/16 in. thick. The side frames are ⅞ in. thick, and are shaped out of the solid. The wheels are 4 ft. diameter and have weldless steel tyres, the flanges of the middle wheels being turned thin to facilitate passing round sharp curves. The axles are of best hammered scrap iron 5½ in. diameter in the journals; the axle boxes are of the usual construction, and are provided with efficient means for lubrication. The cylinders (14 in. by 22 in.) are of best cold blast cylinder metal. The pistons are fitted with Ramsbottom steel springs. The piston rods are of best hammered scrap iron, and are cottered into wrought-iron crossheads: the cylinders are fitted with lubricators and waste-water cocks with levers. The connecting rods and coupling rods are of hammered scrap iron, and have heavy brasses secured by adjustable cotters. The slide bars are also of best hammered iron, and are case-hardened. The engine is complete with feed pump and injector, a powerful screw brake, sand box on each side of the boiler, and cab over the footplate. The buffer beams are of best well-seasoned English oak, and the bearing springs, spring buffers, draw springs, hooks, coupling chains, &c., are all of the best quality. Each engine is supplied with a tool chest containing a set of spanners, one moveable spanner, one copper hammer, one lead

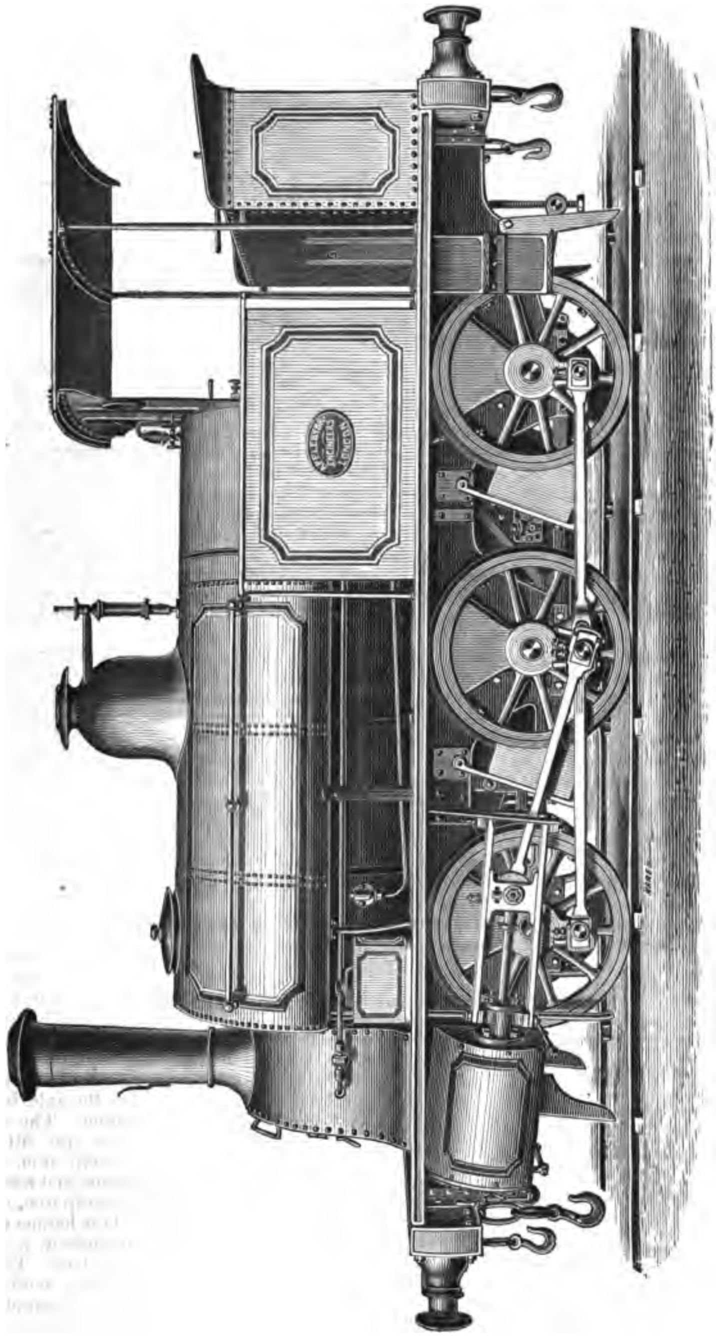


Fig. 16.

hammer, one hand hammer, two hammers, three files, three chisels, spare gauge glass, two oil cans, and one crow-bar. A complete set of firing irons and shovel is also supplied.

Prices, &c., of Tank Locomotives, Fig. 16.

Diameter of cylinder	9"	10"	11"	12"	13"	14"	15"	16"
Length of stroke	14"	18'	18"	18"	20"	20"	22"	22"
Number of wheels..	4	4	6	6	6	6	6	6
" " coupled ..	4	4	6	6	6	6	6	6
Diameter of driving wheels ..	2' 6"	2' 10"	3' 1½"	3' 1½"	3' 6"	4' 0"	4' 6"	4' 6"
Length of wheel base	5' 0"	4' 9"	9' 6"	9' 6"	9' 8½"	12' 0"	13' 3"	13' 3"
" engine over buffers ..	16' 6"	19' 6"	23' 0"	23' 0"	22' 6"	28' 0"	28' 0"	28' 0"
Price of engine complete in running order	£800	£1000	£1200	£1300	£1450	£1650	£1850	£2000
Weight of engine, empty, in tons	9	10½	11¾	14¾	17¾	24	26	27¾
Measurement in c. ft. when packed	800	1100	1100	1500	1800	2700	2900	3200

TANK LOCOMOTIVE, 2 ft. 8 in. gauge, Figs. 17 to 19. The engravings and the subjoined description of this engine are copied from *Engineering* of January 20, 1871. Since then many engines of this type have been made, and they have fully borne out the opinion expressed by the writer of the subjoined extract:—"This little engine has outside cylinders " 8 in. in diameter, with 15 in. stroke, these cylinders being placed at an inclination of 1 in 5, " and being situated at a distance apart, transversely, of 4 ft. 2 in. from centre to centre. The " engine is carried on two pairs of coupled wheels 2 ft. 3 in. diameter, and placed 5 ft. apart " from centre to centre, this short wheel base being adopted to allow the engine to traverse " freely the sharp curves met with on the line. The valve gear is arranged externally, as " shown in the perspective view, the eccentric being placed on an overhung crank. The " boiler is 2 ft. 8 in. in diameter inside, and 7 ft. 6 in. long from smoke-box tube-plate to back " plate of fire-box casing. The fire-box casing is 3 ft. 6 in. long, and extends 2 ft. 11 in. below " the centre line of boiler at the front, and 1 ft. 10½ in. at the rear end. The width of the fire- " box casing at the lower part is 2 ft. 2 in., its form being shown by the transverse section. " The fire box is 3 ft. long by 1 ft. 8½ in. wide, and has a mean height of 2 ft. and ½ in. above " the fire grate. The boiler contains 72 tubes, 1½ in. diameter by 4 ft. 2 in. long between the " tube plates, the external tube surface being thus 117½ square ft. The fire-box surface is " about 23½ square ft., thus making the total surface 141 square ft. The grate area is 5·13 " square ft. The engine has inside and outside frames, the total width outside being 5 ft. 3 in., " and the total length over buffer beams 12 ft. 11 in. The arrangement of the springs, and " details generally, are so clearly shown in the views we publish, that it will be unnecessary for " us to describe them. The fuel is carried in bunkers arranged at the sides of the fire box, and " the water in a tank at the trailing end. The boiler is fed by a pair of injectors, arranged as " shown in the perspective view. Altogether Messrs. Appleby Brothers have produced a handy " little engine, which will no doubt do its duty well."

The engine with 8-in. cylinders takes a load of about 30 tons up an incline of 1 in 70; those with 9-in. cylinders will draw about 100 tons on the level.

Prices, &c., of Tank Locomotives, Figs. 17 to 19.

Diameter of cylinder	8"	9"	10"
Length of stroke	15"	16"	18"
Number of wheels (all coupled)	4	4	4
Diameter of wheels	2' 3"	2' 9"	3' 0"
Length of wheel base	5' 0"	5' 0"	5' 6"
Length of engine over buffers	12' 11"	13' 0"	14' 0"
Price of engine complete, in running order	£750	£800	£950
Approximate weight of engine, empty, in tons	8	9	10
" measurement of engine in cubic feet ..	750	850	1000

The cost of packing will vary according to circumstances, but will seldom exceed 5 per cent. There is but little increase in cost for engines of wider gauges up to 3 ft. 6 in.

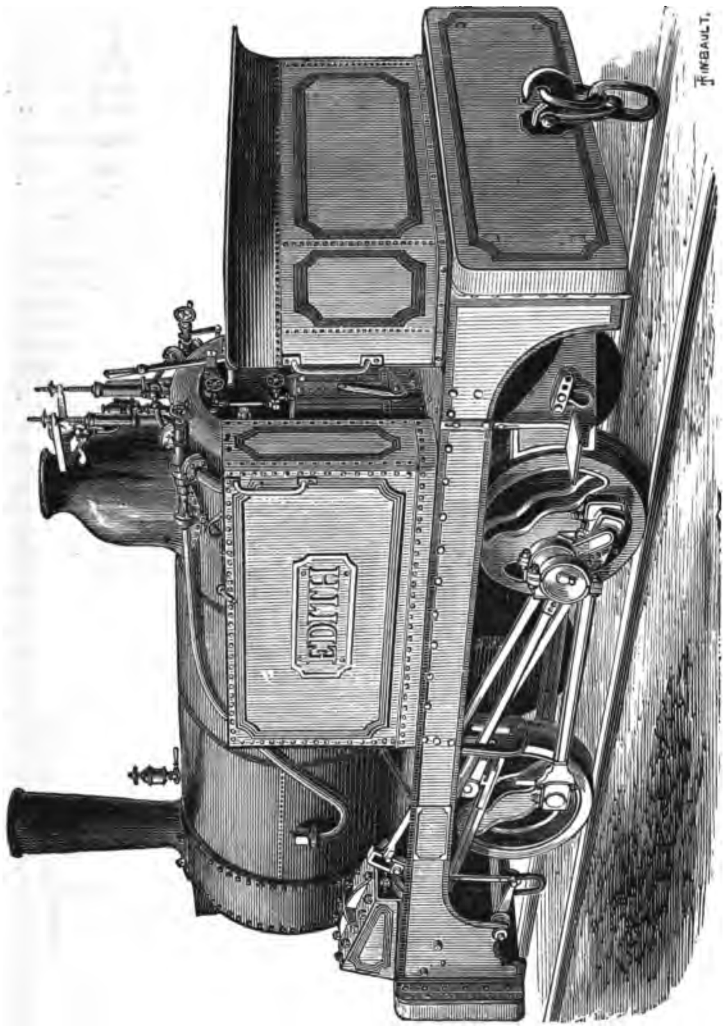


Fig 17. (*For description, &c., see pages 20 to 25.*)

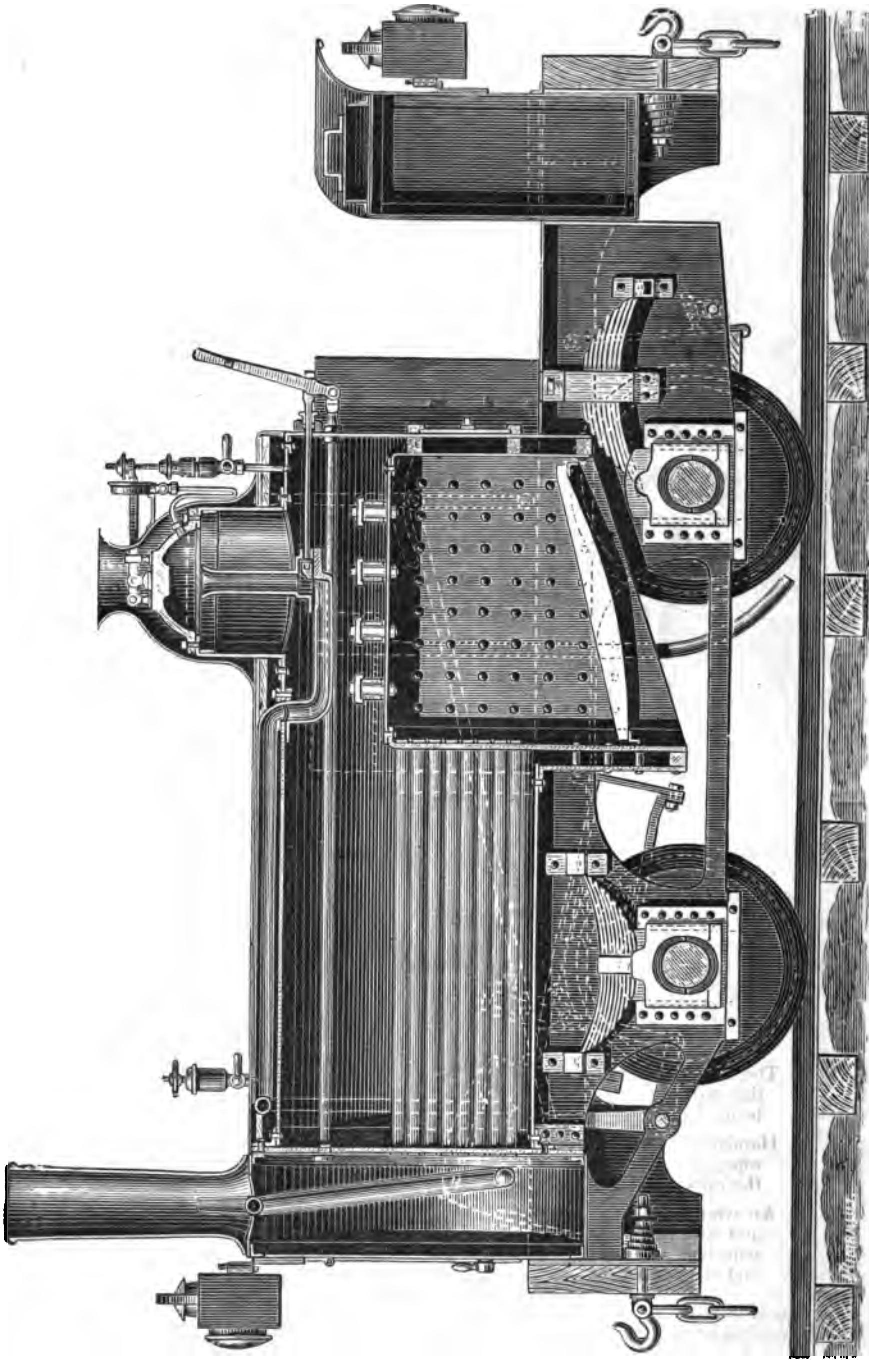


Fig. 18. Longitudinal Section.

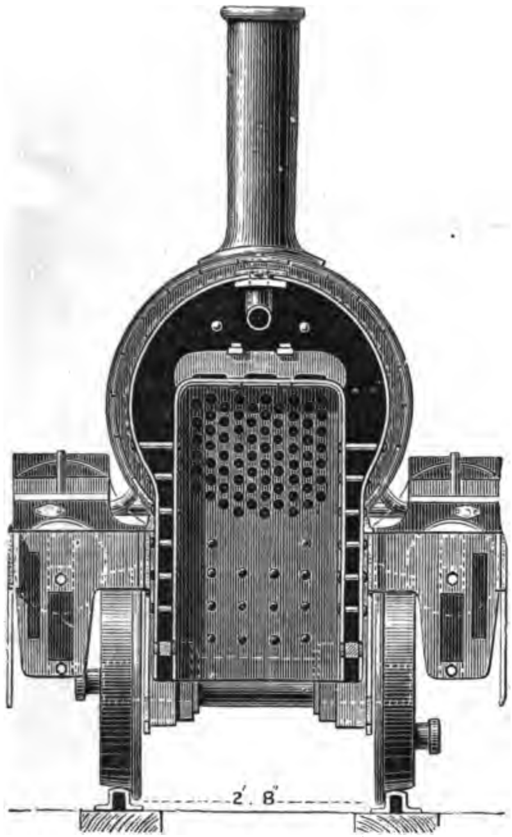


Fig. 19. *Cross Section.*

LOCOMOTIVES FOR STEEP GRADIENTS. Apart from the locomotive of the ordinary type, which depends for tractive force on the adhesion of the wheels to the rails, and which is insufficient for the very steep gradients exceptionally used in Switzerland and some parts of Austria, there are—

1. The Fell system, which has been worked on a large scale, with (owing to a variety of causes) but moderate success.
2. The Righi Railway, where a spur pinion gearing into the rack laid centrally between the rails, has been successfully used for some years past, the maximum gradient being 1 in 4.
3. Handyside's system, in which the locomotive, provided with a winding-drum and wire rope, proceeds up the incline in advance of the train, and after being anchored to the rails, draws the train up by the wire rope.
4. An arrangement designed by the Authors, in which a chain was laid between the rails, and was passed over a chain wheel of the same diameter at the pitch line as the wheels of the locomotive; the engine would therefore haul by adhesion on the level, and lay hold of the chain when going up or down steep gradients.

For most of these engines vertical boilers have been used on account of the small wheel base which can thus be obtained, and because this form is in other respects more favourable for use on steep gradients.

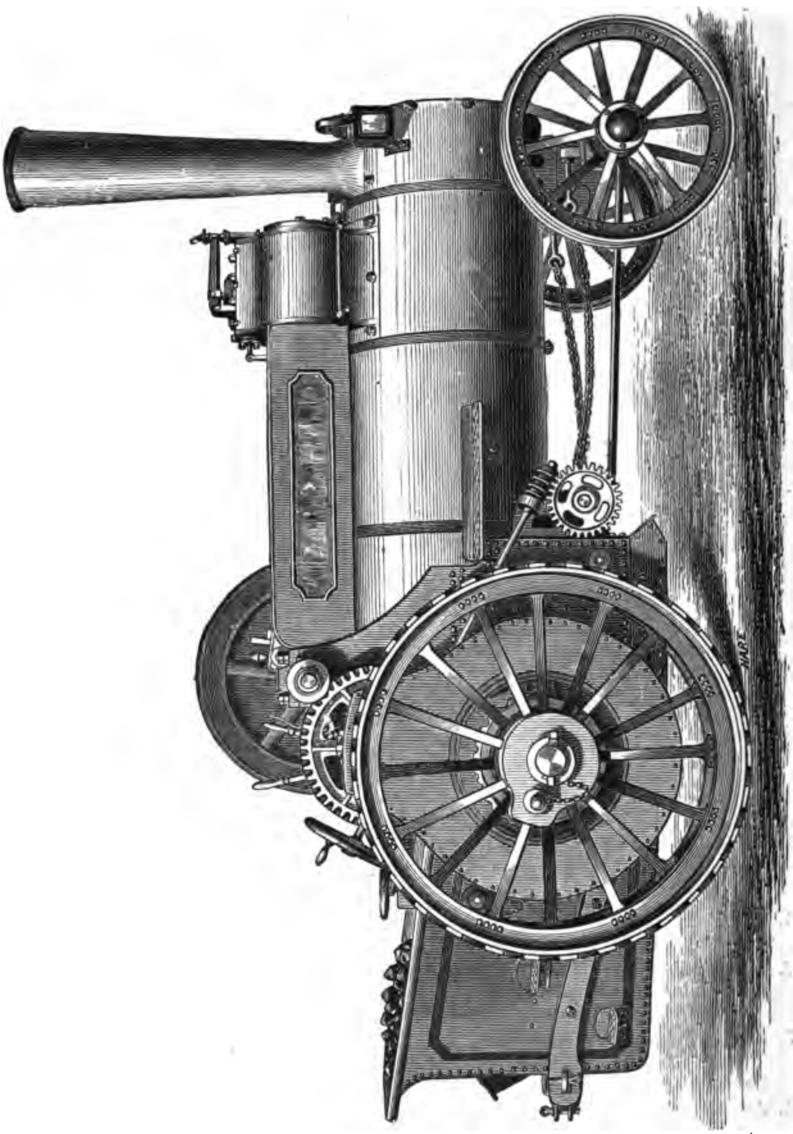


Fig. 20.

ROAD LOCOMOTIVE, or TRACTION ENGINE, Fig. 20. Although the use of this class of engine has been almost entirely abandoned for passenger traffic, it has gradually extended for hauling heavy loads, and several hundreds are now employed with marked economy in farming operations, contractors' work, mining, and other industries. The engine illustrated has one cylinder, steam-jacketted, and connected with the steam dome, which avoids the necessity of steam pipes, the connecting-rod is of wrought iron fitted with gun-metal bearings, straps, and adjusting cotters, the crank shaft runs in adjustable bearings, which, together with the bearings for the countershaft and driving axles, are carried in wrought-iron brackets formed in one piece with the side plates of the fire box, which are carried forward and upward for that purpose. This arrangement is strong and neat, it reduces the strains on the boiler, and avoids the risk of leakage, which is incurred in bolting brackets up to a boiler. The engine is steered by the worm gear and chains, as shown in the engraving, through a hand wheel placed over the foot plate, so that it is entirely under the control of one man; formerly one man was required to steer and another to stoke and drive. The engine is so designed that 85 per cent. of the whole weight is carried on the driving axles; this not only gives great tractive force, but relieves the boiler from strains which would come on it from jerks occasioned in passing over rough roads. The driving-wheels are of wrought iron with diagonal strips on the face, and are provided with a compensating motion for turning sharp curves without disconnecting either wheel; and both wheels being in gear, each does its fair proportion of the work. If preferred (and under some circumstances, it is highly desirable) spring tire wheels, on the system invented by the late Mr. W. B. Adams, may be substituted for the wrought-iron wheels just described, at a slightly increased cost; these wheels consist of an inner tire of strong tee iron rivetted to the spokes, and an outer tire of plate iron stiffened on the edges by angle iron rings, and carrying diagonal strips on the face to increase the tractive power, and take the paddles sometimes required in traversing very soft ground. Between these tires solid india-rubber is packed, forming a spring, and thus greatly reducing the jerks and strains to which the engine is subjected. The tires are connected by a drag link, so that they cannot slide on the india-rubber. The boiler is multitubular, tested to a pressure of 200 lbs. per square inch, and furnished with feed apparatus and all furnace and steam fittings necessary for economical and safe working, including a steam-pressure gauge, and extra safety valve, a complete set of wrenches, screw hammer, firing tools, oil can, spare gauge-glasses, and driving-wheel studs. The coals are carried in a bunker at the back of the foot plate. A strong jib, fixed to the fore part of the engine, by means of which loads up to 2 tons may be lifted with safety, greatly increases the usefulness of these engines for use under the conditions referred to below.

Nominal horse power	4	6	8	10	12
Diameter of cylinder	6¾″	8½″	9½″	10⅛″	12″
Length of stroke	10″	12″	12″	12″	14″
Price complete, in running order	£395	£445	£510	£580	£660
Extra, if fire-box be large enough to burn wood	£10	£10	£10	£15	£15
Packing for shipment	£8	£10	£15	£20	£25
Approximate weight in cwts.	90	120	140	160	180

WAGGONS SUITABLE TO WORK WITH TRACTION ENGINES.

Load in tons	4	6
Price, complete with iron or wood wheels	£66	£72
Price of a set of iron work for iron or wood wheels	£45	£50
Price of screw brake	£3	£3
Packing for shipment, each waggon	£2	£2

The waggons are specially constructed for carrying minerals and agricultural produce over ordinary roads, and the couplings are arranged to allow the waggons to turn very sharp curves.

TRACTION ENGINE WITH CRANE JIB. The engines above referred to are also made with a crane jib, which is fitted to the locking carriage of the front wheels and tied back to the wrought-iron brackets carrying the gear; the lifting chain coils on a barrel fixed below the water tank, and is driven from the engine with suitable gear, lifting, lowering, or holding the load suspended when the engine is travelling. This engine possesses many advantages for use

in dockyards, quarries, and for military purposes. The whole of the operations, driving, steering, lifting, &c., are controlled by one man.

Horse power	4	6	8
Price	£435	£505	£590

The weights and measurements will be a little in excess of those given on page 27.

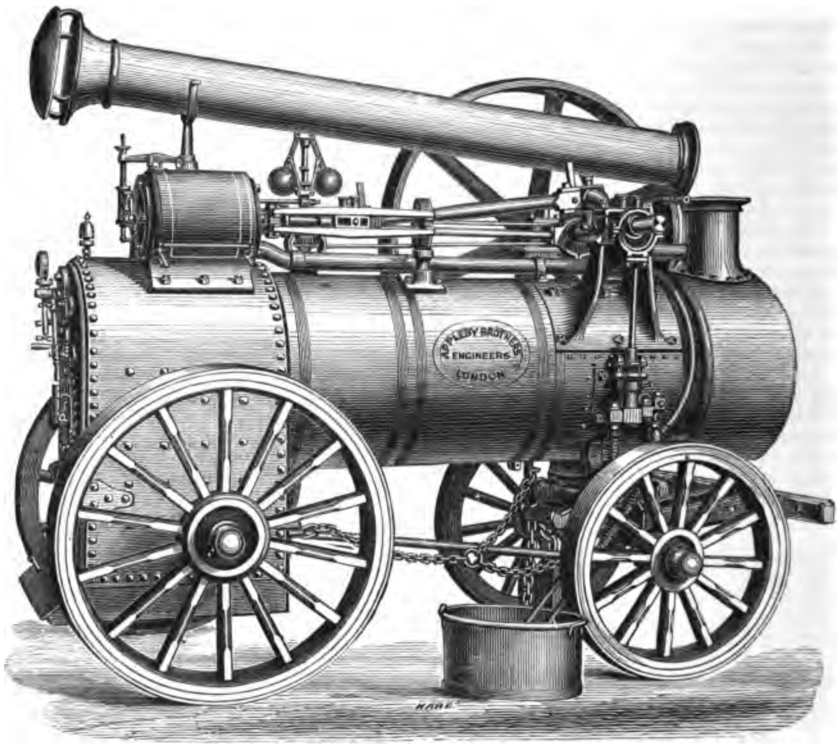


Fig. 21.

PORTABLE STEAM ENGINE, Fig. 21. The ample experience which has been gained with portable engines working under very varied conditions, has led to the adoption of many important improvements in their design and proportions, more particularly with a view of ensuring economy in the consumption of fuel, and of obtaining increased durability.

The competitive trials held under the auspices of the Royal Agricultural Society have greatly assisted in promoting excellence of design and workmanship, and the engine illustrated, Fig. 21, is equal to any portable engine obtainable. In practice the full power of a portable engine is seldom exerted, and in ordinary engines much fuel is wasted, because the supply of steam to the cylinder can only be regulated by throttling the starting-valve, a very wasteful method, producing what is technically termed "wire drawing"; but this is avoided by the application of a very simple expansion gear, by which the moment of cutting off the steam supply to the cylinder may be regulated at any point, from one quarter of the stroke to full stroke. This arrangement requires only one eccentric and one slide valve, and is not subject to derangement; and as might reasonably be expected a very marked saving in fuel is obtained. As a further safeguard against waste of fuel, a water heater is provided, whereby the heat of the exhaust steam is made to raise the temperature of the feed water to a high point before it is forced into the boiler. The cylinders are steam-jacketted, and the boilers are of the multi-tubular locomotive type, of ample dimensions, best workmanship, and materials throughout, and

stayed for a high-working pressure. The fire box is entirely of Lowmoor iron, and of ample dimensions for burning coal or coke; but if (owing to the high price of these fuels where the engine is to be used, or any other cause) it be considered desirable to make provision for burning lignite or wood, the boilers can be made with extra-large fire boxes, at the slightly-increased cost indicated in the price list. A reversing motion is fitted to each engine by means of which it can be made to run in either direction, but the engine can be provided with link reversing gear, if it is required for such work as winding, &c., and the cost of this is given in the lists. The cross head is guided by two blocks, sliding between two pairs of cast steel bars; one end of these bars is carried on the cylinder gland, and the other on a special casting bolted to the barrel of the boiler. The connecting-rod is of scrap iron, fitted with strap heads, and gun-metal bearings; the lubricators on this and all other parts of the engine are worked out of the solid metal. The wrought-iron bent crank shaft is of such a length that power may be taken off from either or both ends, and runs in wide adjustable gun-metal bearings; these bearings are carried in a cast-iron saddle bracket, fixed to the fore part of the barrel of the boiler. A heavy cast-iron fly-wheel is keyed on the crank shaft. The chimney is provided with a spark catcher, and hinged as shown. When thrown back, it rests on a forked bracket carried on the cylinder; this arrangement enables the engine to be taken under a low archway, or into a shed when not required for immediate use. Every engine is fitted with a neat and efficient governor, and a verticle plunger feed pump; but, if preferred, a Giffard's injector will be fitted instead of this pump, when the cost will be slightly increased. The whole is mounted on wood or iron travelling wheels (the former being preferable excepting for use in tropical climates), with patent axles, locking plate and shafts, check chains, lock chains, and shoe; and is complete as shown, with all furnace and steam fittings, including a patent steam-pressure gauge, double safety valves, one being locked up, steam whistle, and suction hose for pump with copper rose, also firing tools, funnel, oil feeder, spanners, and waterproof cover. It is recommended that the following spare parts be ordered with all engines intended to be used in remote districts: gun-metal bearings for crank shaft, and for connecting-rod ends, one set of piston rods and springs, one set of furnace bars, six gauge glasses and rings, one tube brush, three boiler tubes with steel ferrules for same, and one length of suction and one length of return hose, one set of eccentric clips and bolts. The cost of these spare parts is six per cent. on the price of the engine.

Head and Schemioth's apparatus for firing with straw, cotton, wood, or other vegetable matter is invaluable in some countries, and can be applied at an extra cost of £70 to £80.

SINGLE-CYLINDER PORTABLE ENGINES.

Nominal horse power	2½	3	4	5	6	7	8	9	10	12
Number of revolutions per minute ..	180	180	150	125	125	125	125	125	110	110
Price complete	£105	125	150	165	180	195	210	225	240	280
Extra for fire box for burning wood ..	£2 10	3	4	5	6	7	8	9	10	12
Packing for export	£2 10	3	4	5	6	7	8	9	10	12
Approx. weight of engine only in cwts.	30	45	52	64	72	80	84	103	112	119
„ „ packed „	37	53	61	74	84	92	95	115	126	134
„ measurement „ in cub. ft.	155	208	256	285	334	349	390	443	457	501

DOUBLE-CYLINDER PORTABLE ENGINES.

Nominal horse power	8	9	10	12	14	16	18	20	25	30
Number of revolutions per minute ..	125	125	125	125	125	125	95	95	95	95
Price complete	£235	250	265	305	340	375	410	450	540	640
Extra for fire box for burning wood ..	£8	9	10	12	14	16	18	20	25	30
Packing for export	£8	9	10	12	14	16	18	20	25	30
Approx. weight of engine only in cwts.	94	107	115	118	125	132	198	213	233	263
„ „ packed „	107	118	126	130	138	147	216	235	255	285
„ measurement „ in cub. ft.	390	409	423	465	472	491	570	630	710	790

The extra cost of a Giffard's Injector in place of feed pump varies from £5 to £12, and the cost of link reversing motion varies from £15 to £25, according to size of engine.

PORTABLE VERTICAL STEAM ENGINE, WITH VARIABLE EXPANSION, Fig. 22. In localities where the feed water is highly impregnated with insoluble matter, the water spaces between the tubes of multitubular boilers frequently become choked with solid deposit to such an extent as greatly to impair the value of the tube-heating service, eventually leading to considerable expense and loss of time in repairs, &c. In such situations a plain Vertical Boiler of the type illustrated (all parts of which are easily accessible for examination) may be used with advantage; and many years' experience has shown that under these conditions, or

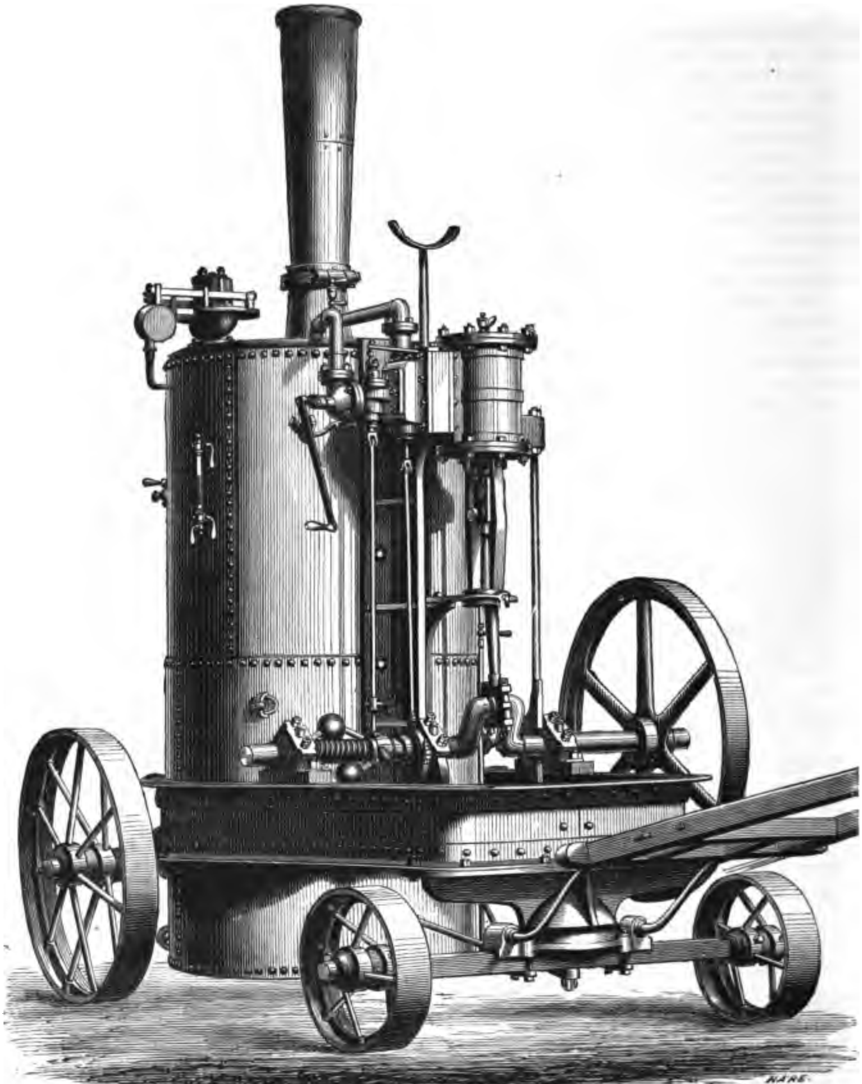


Fig. 22.

where wood or inferior fuel is used, boilers of this construction give a better working result than the ordinary multitubular class.

The fire box has one or more cross water tubes according to the size of the boiler, and the smoke tube forms a stay between the crown of the fire box and the shell of the boiler; there is a hand-hole and cover opposite each cross tube for clearing it of any deposit which may have been formed.

The boiler is fitted with the usual furnace mountings, chimney with joint to turn down when travelling, damper, man-hole strengthened round the edge, and mud-holes round the bottom of shell.

The water and steam fittings consist of water gauge, two gauge cocks, blow-off cock, double safety valves, one being dead-weighted and locked up, steam pressure-gauge and regulating valve.

The boiler is fed by a gun-metal pump, worked from the engine shaft, with the usual gun-metal valves, regulating cock, flexible suction-hose and strainer; or if preferred, a donkey steam feed-pump may be supplied with apparatus for working by hand when required, at an extra charge of about £5.

The steam cylinder, valve box, guides and central bearing are carried on a strong girder, which rigidly ties together all the working parts, and takes the strain off the shell of the boiler; and, in addition to the ordinary slide-valve motion, the engine is fitted with a *variable expansion gear*, worked direct from the governors, ensuring the highest duty possible from a given weight of steam. The eccentric straps are of gun metal, the connecting-rods are fitted with gun-metal heads of the marine-engine pattern, and the details of the engine work are carried out in the best style.

The crank shaft is of wrought iron, and is of sufficient length to take a pulley on either end, and the fly-wheel is turned on the face to take a strap.

The frame is of wrought iron, and carries the end crank-shaft bearings and the conical locking-plate of the front axle; the hind axle is curved round the back of the boiler, and is attached to the under side of the frame, which relieves the boiler of strain when travelling, and both can be readily removed for packing and shipment. The axles are of wrought iron, the wheels of iron suitable for hot climates, unless preferred of wood, and the shafts can be made in iron or wood suitable for horse or bullock traction.

PRICES, &c., OF VERTICAL PORTABLE ENGINES, Fig. 22.	SINGLE CYLINDER.						DOUBLE CYLINDER.		
Nominal horse power	3	4	6	8	10	12	6	8	12
Diameter of cylinder	5½″	6½″	7¼″	9″	10″	11″	5½″	6½″	7¼″
Length of stroke	9	10	12	12	12	15	9	10	12
Number of revolutions per minute	180	150	125	125	125	115	180	150	125
Price of engine complete, with governor ..	£117	163	202	241	280	320	230	281	365
Extra for link-motion reversing gear ..	7	8	10	11	12	12	15	18	20
Extra for felting and lagging boiler ..	10	12	13	15	16	16	13	15	17
Approximate weight in cwts., packed ..	40	50	65	75	85	95	70	80	100
„ measurement in cubic ft. ..	150	160	300	380	450	500	300	390	510

Packing fo shipment 3 to 5 per cent. Engines under 8-horse power are not fitted with variable expansion.

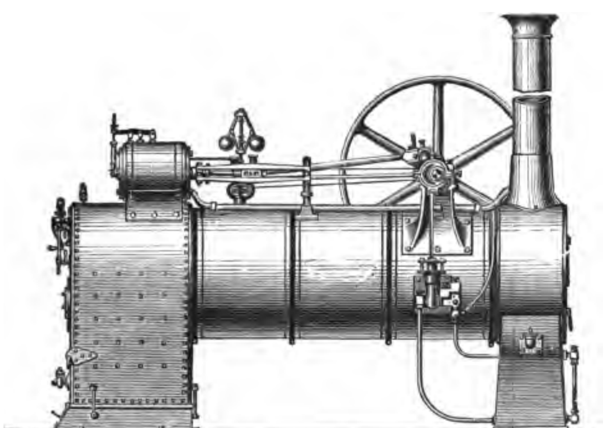


Fig. 23.

HORIZONTAL SEMI-FIXED STEAM ENGINE, Fig. 23. The construction of both engine and boiler is exactly the same as the Portable Engine, Fig. 22; but instead of being fitted with wheels and fore carriage, the smoke-box end of the boiler is carried on a feed-water tank, and it may be put down on timber or brickwork, and in many places no special foundation is required. Engines of this kind occupy but little space, and can be fixed in any building, the chimney being lengthened to pass through the roof if necessary.

PRICES OF HORIZONTAL SINGLE-CYLINDER SEMI-FIXED ENGINES, Fig. 23.

Nominal horse power ..	2½	3	4	5	6	7	8	9	10	12
Price complete	£120	£145	£175	£190	£210	£225	£245	£265	£280	£320

PRICES OF HORIZONTAL DOUBLE-CYLINDER SEMI-FIXED ENGINES.

Nominal horse power ..	8	9	10	12	14	16	18	20	25	30
Price complete	£275	£290	£305	£355	£400	£440	£495	£530	£640	£755

The dimensions, weights, number of revolutions, and cost of link reversing motion, &c., are the same as given in the Lists of Portable Engines. See p. 31.

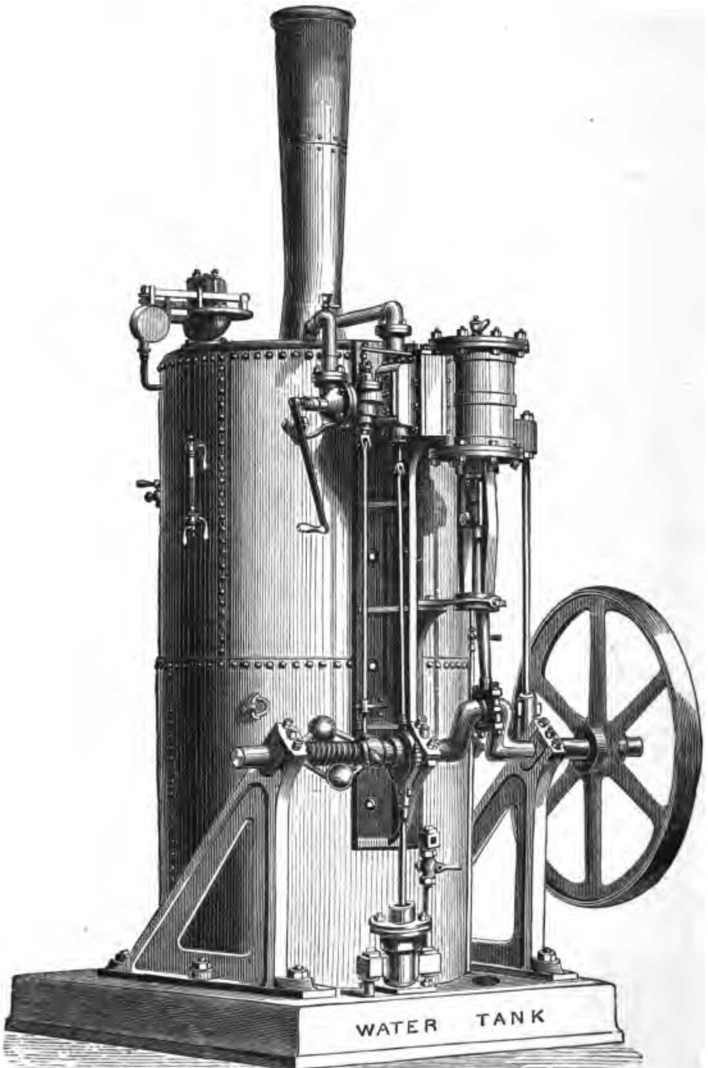


Fig. 24.

VERTICAL SEMI-FIXED STEAM ENGINE, Fig. 24. The engine and boiler are similar to the Portable Engine, Fig. 21, but the engine is mounted on a cast-iron base-plate, which serves as an ash-pan and water-tank. The outer bearings of the crank shaft are carried by two cast-iron brackets, fitted with gun-metal adjustable bearings, the engines above eight horse-power having a self-acting variable expansion. The engine may be placed on timber, brick-work, or stone foundations, and set to work without the previous preparation of expensive foundations.

PRICES OF VERTICAL SEMI-FIXED STEAM ENGINES, Fig. 24.

	SINGLE CYLINDER.						DOUBLE CYLINDER.		
Nominal horse-power	3	4	6	8	10	12	6	8	12
Price, complete	£110	£150	£180	£215	£255	£280	£210	£255	£330

The dimensions, weights, &c., are nearly the same as the Vertical Portable Engine, Fig. 23. Extra for link motions, lagging, &c., same as for Vertical Portable. (See p. 31.)

OSCILLATING PADDLE ENGINE, Fig. 25. This type of paddle engine has been used more than any other, on account of the large power which can be provided in a very limited space; the piston rods working direct on to the crank pins, there is little loss by friction, excepting that due to the friction of the trunnions. The steam enters the cylinders through the outer trunnions, and, when it has done its work, passes through the inner trunnions to the condenser; the air-pump is driven off a crank central between the two cylinders, and the two feed-pumps are worked by eccentrics on the paddle shaft. The bearings for the paddle shaft are carried on a strong entablature, which is supported on wrought-iron stays or columns from a massive iron base plate.

A very large number of these engines are employed in the passenger traffic on the Thames and on many foreign rivers, and that they are equally adapted for sea-going steamers is shown by the fact that they are almost exclusively fitted to the vessels plying with such extraordinary regularity between Dover and Calais, Dover and Ostend, Folkestone and Boulogne, &c., even in the worst weather.

The form of the framing is such, that whilst being light, there is ample strength to resist the severe strain caused by the work being suddenly thrown on one paddle, whilst the next moment the deep immersion is sufficient to greatly retard the normal speed of the engine. The materials and workmanship are of the highest character, and the subjoined approximate values include the usual fittings, steam and vacuum gauges, apparatus for lubrication, all conveniently placed within the observation of the chief engineer.

Nominal horse-power	60	120	180	260
Diameter of cylinder	18″	24″	30″	36″
Length of stroke	18″	24″	30″	36″
Number of revolutions per minute	100	75	60	50
Price of engine, complete	£1080	£2160	£3240	£4500
Prices of suitable boilers with fittings ..	£900	£1800	£2600	£3400
Approximate weight in tons, packed ..	25	50	70	90
" measurement in cubic feet ..	900	1700	2500	3000

These prices do not include piping, connections, &c., between the engine and boiler, nor paddle wheels. Cost of packing about 5 per cent.

DIRECT-ACTING SCREW ENGINES, AND BOILER, Fig. 26. The engines of this type, for vessels up to 300 tons, have inverted steam cylinders carried on strong hollow standards, which also form the guides for the cross heads; the slide valves are between the cylinders, and the valve box cover is on the side, giving easy access to the valves for examination, &c. The engines have

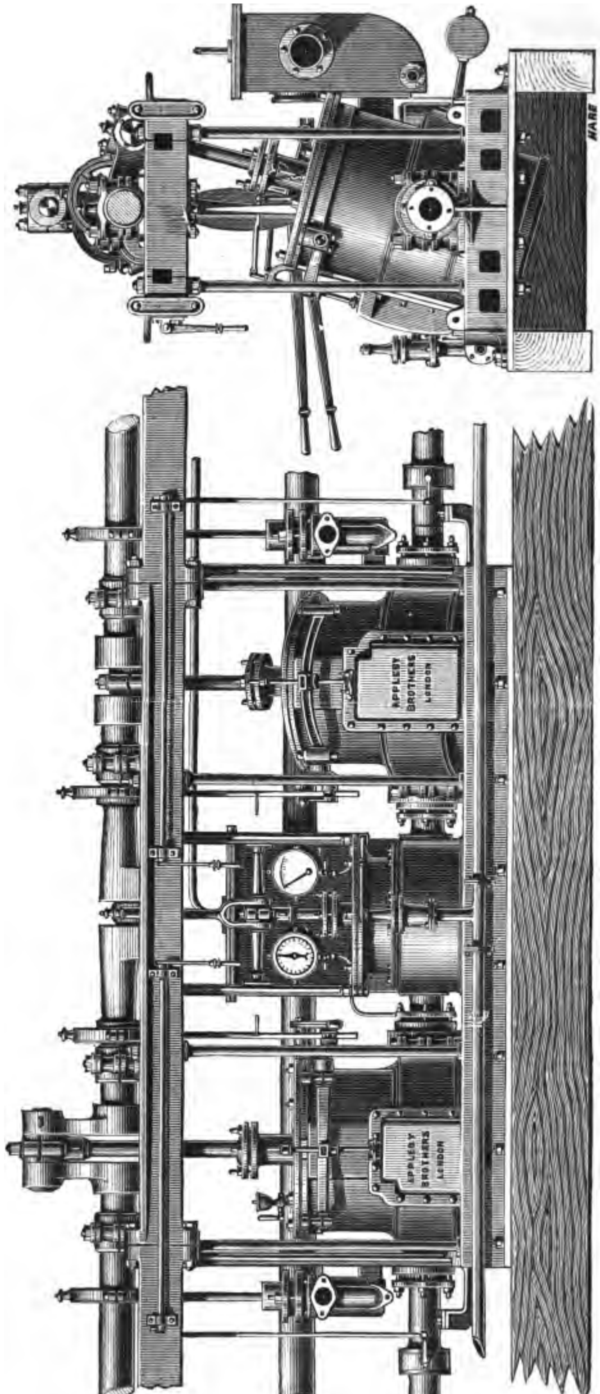


Fig. 25.

case-hardened link motion reversing gear and separate expansion valve, ensuring an economical distribution of steam. The condenser is fixed on one side; the air pump is driven by side levers from the cross head of the engine, and the whole arrangement is neat and compact. The standards which carry the engines are fixed to a strong cast-iron base plate of the form shown in the Engraving; the bearings for the crank shaft, including the thrust bearing, are also secured to this plate. The screw shaft is coupled direct to the crank shaft, and passes through a stern tube as shown. It is usually fitted with a three-bladed screw propeller, but any other form may be adopted, and the propeller is made of malleable cast iron, gun metal, or cast steel, as may be desired, the price varying according to the material employed. The boiler is of the ordinary circular form, with an internal flue and return tubes, the uptake leading to the chimney being in front of the boiler and directly above the fire door. The boiler is of the best material and workmanship throughout, and is furnished with all the steam mountings and furnace fittings necessary for its safe, efficient and economical working. A donkey pump for feeding the boiler is shown on the left hand side of the engraving of cross section. The prices of these engines will be proportionate to those given on pages 33 and 37, but they must necessarily vary considerably, the engines and boilers being almost invariably designed to suit the vessels for which they are intended.

COMPOUND MARINE ENGINES.—Very economical results have been and are being obtained from compound marine engines. Many arrangements have been tried, but the engines with one high and one low pressure cylinder, or one high pressure and two low pressure cylinders are those which have given the greatest economy, especially in ocean-going steamers, when the consumption of fuel is of far greater importance than the difference in first cost, this type of engine being necessarily more expensive than those working high pressure only. The first-named construction (one high and one low pressure cylinder) is more used than that with three cylinders; the proportion of the low-pressure cylinder is from 3 to 4 times the capacity of the high-pressure cylinder, and the advantages are, that engines of comparatively small dimensions and weight develope a given power with a much lower consumption of fuel than high-pressure engines.

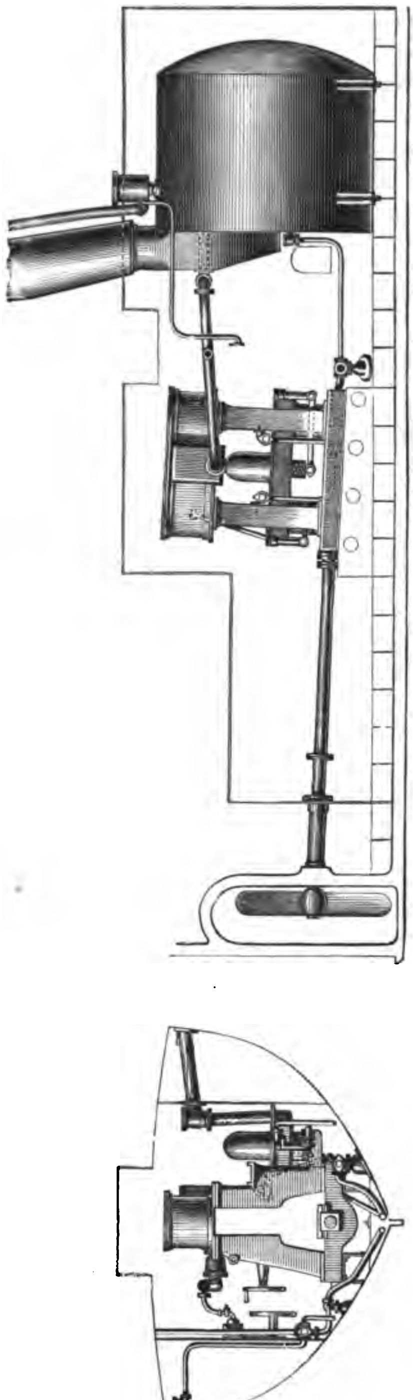


Fig. 26.

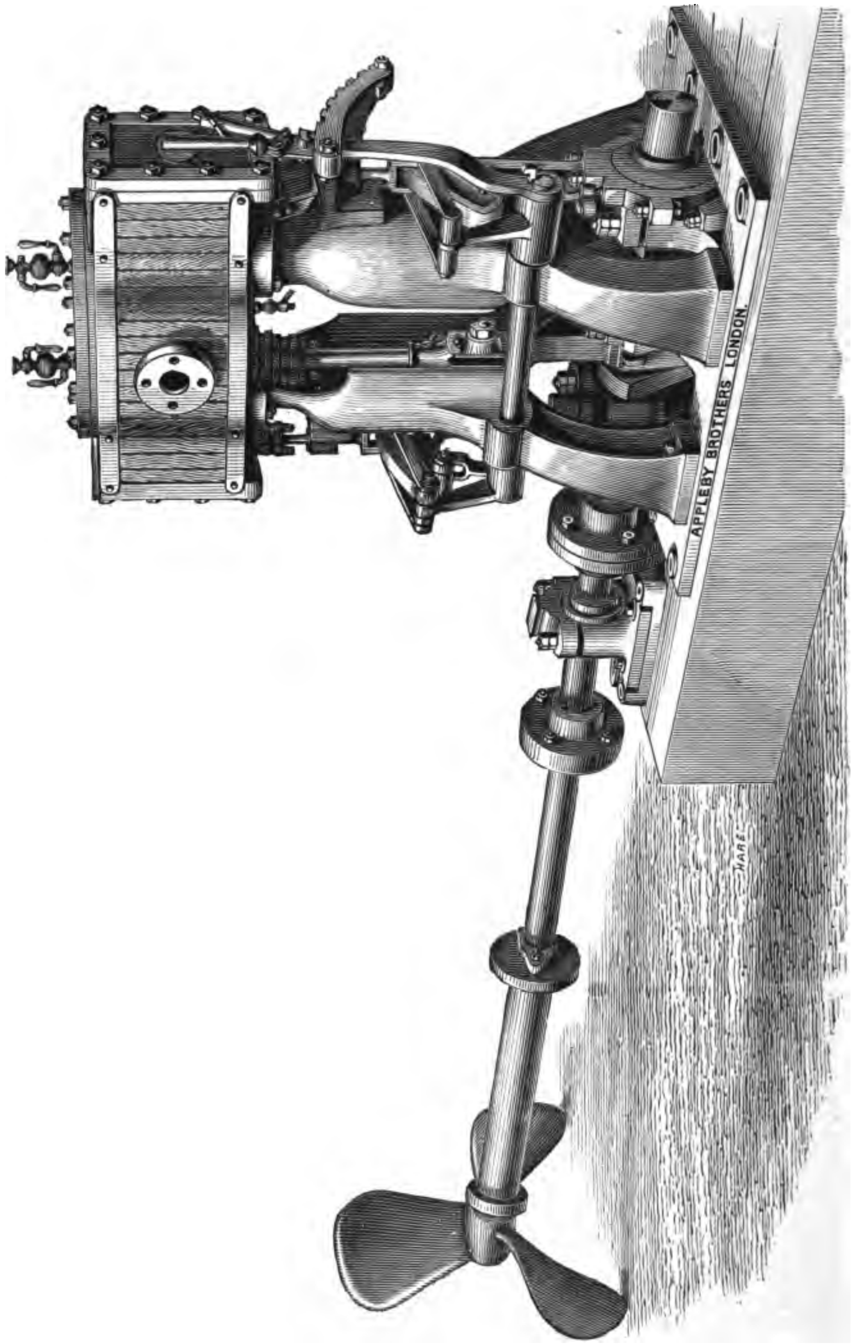


Fig 27.

VERTICAL YACHT ENGINE. The great increase in the number of yachts, small tug-boats, and steam lighters, in use on rivers for business and pleasure, has led to the production of engine, Fig. 27. It is neat, compact, and strong, and has been designed with a view of taking up as little head room as possible. The engraving, taken from a photograph, shows a double-cylinder engine, but prices are given below of both single and double cylinder engines of this class. The same design is adopted for all the smaller sizes enumerated in the list, but is somewhat modified in the larger sizes. The two cylinders and valve boxes are cast in one piece, the valve boxes being turned outwards, and therefore being quite accessible for examination. The standards carrying the cylinders are massive iron castings, forming the guides for the crosshead; they are bolted to a cast-iron base-plate carrying all the bearings including the thrust bearing. The pistons are metallic, with rings and springs, the piston rod of steel, the cross head adjustable, and the connecting-rod of wrought iron, fitted with adjustable gun-metal bearings. The crank shaft and screw shaft are of scrap iron, and run in extra long gun-metal bearings. The screw propeller is of the ordinary three-bladed description, and may be had either in gun metal, cast iron, malleable cast iron, or steel, the price varying according to the metal employed. The stern tube is of cast iron of suitable length for a single screw boat, but where twin screws are employed, or in some other cases, it would require to be lengthened. The engines are fitted with double eccentrics and link reversing motions, the hand lever being provided with spring bolt and notched quadrant, for holding it in any desired position. A suitable feed pump is provided with each engine, and the design, materials, and workmanship of both engines and boilers are of the highest class. The boilers are of the type illustrated in Fig. 28, which give economical results, and occupy small space.

DOUBLE-CYLINDER ENGINES.

Nominal horse-power	3½	5	7	8	10	14	18	24	30	40
Diameter of each cylinder	4"	5"	6"	6½"	7"	8"	9"	10"	12"	14"
Length of stroke	5"	6"	7"	7"	8"	9"	10"	12"	14"	18"
Number of revolutions per minute ..	300	250	215	215	190	170	150	125	110	90
Price of engine, cast-iron propeller, &c...	£97	120	150	170	195	260	350	390	470	580
Approximate weight in cwt., packed ..	5	9	13	15	18	24	33	43	68	100
„ measurement in cubic ft. ..	10	18	27	30	40	50	66	90	130	220

SINGLE-CYLINDER ENGINES.

Nominal horse-power	2	2½	3	3½	5	7	9	12	15	20	28
Diameter of cylinder	4½"	5"	5¾"	6"	7"	8"	9"	10"	12"	14"	16"
Length of stroke	4½"	5"	6"	6	7"	8"	9"	11"	12"	14"	16"
Number of revolutions per minute ..	320	300	250	250	215	190	170	135	125	110	100
Price of engine, cast-iron propeller, &c.	£58	70	83	85	100	140	170	205	250	330	440
Approximate weight in cwts., packed	3	4	7	7	9	12	15	20	29	42	55
„ measurement in cub. ft.	8	10	15	15	20	25	30	40	60	90	120

It should be remembered that, although for any given power the single-cylinder engine costs rather less, and takes up less keel room, it occupies more head room, and is not so efficient as a double-cylinder engine.

STEAM SCREW TUG with HOIST and FIRE ENGINE. Fig. 28 illustrates a steam tug which serves many purposes, and is worthy of special notice. The total length of the vessel illustrated is 45 ft., the extreme breadth 10 ft., and the depth 7 ft.; and as it was for use abroad, it was constructed to be sent out in sections, and easily fitted together on arrival at its destination. The tug is capable of towing two lighters, each carrying 50 tons, and (by means of the hoist shown in the crankshaft) discharging the cargoes into vessels lying out in the roads. The boiler is of the type generally employed for marine work, and occupies the centre portion of the boat; it is 5 ft. in diameter and 5 ft. long, and has 38 return tubes 2¼ in. diameter. The engines are of the inverted kind, and are placed aft of the boiler, the crank shaft being coupled directly to the screw shaft. The cylinders are 8 in. diameter and 8 in. stroke. The valves are placed between the cylinders, and are fitted with link reversing motion; the crank shaft, piston rods, valve rods, and cross heads, are all made of steel, the

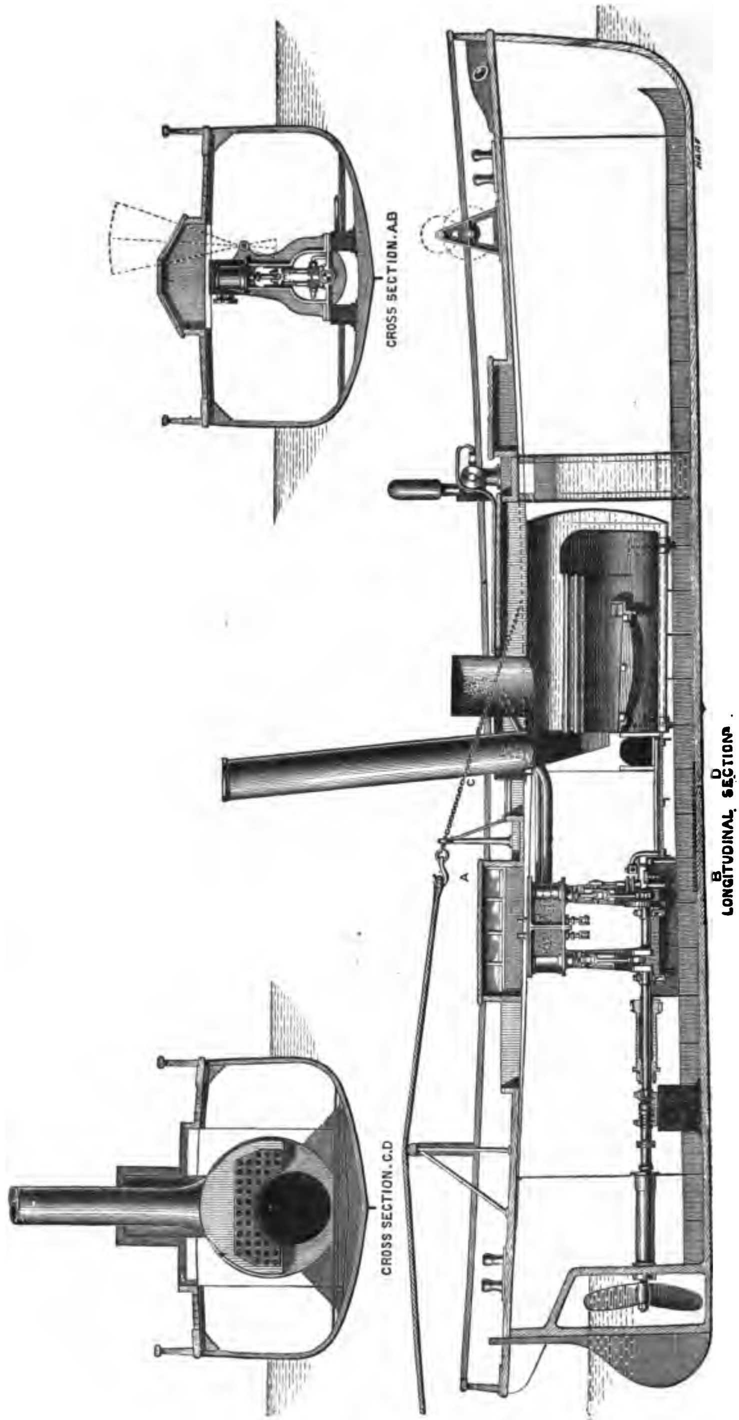

CROSS SECTION. A.B
CROSS SECTION. C.D
LONGITUDINAL SECTION
A
B
C
D

Fig. 28.

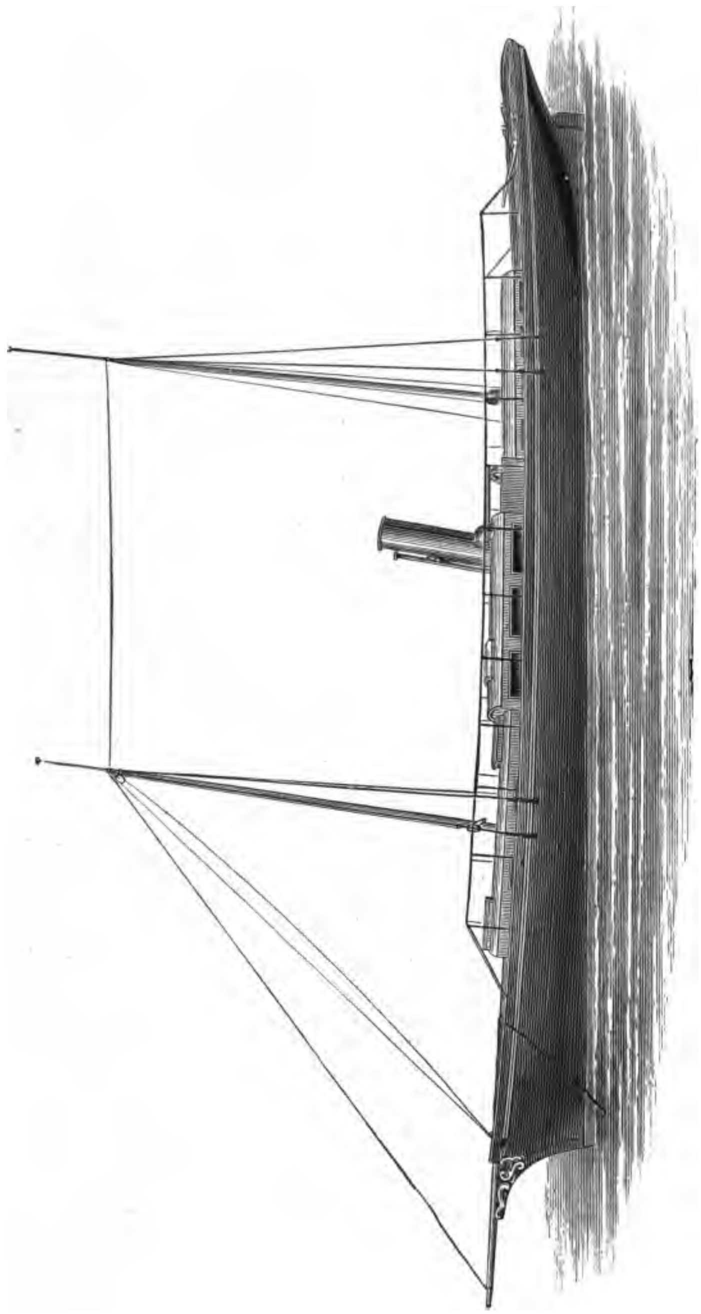


Fig. 29.

eccentric straps, glands, pump plungers, &c., of gun-metal, and the link motions are case-hardened. The screw is of cast iron, 4 ft. in diameter, and has four blades 4½ ft. pitch. The screw shaft is of steel with the thrust collars forged on, and a thrust bearing is provided as shown in the engraving. On the crank shaft between the thrust bearing and the engines is fitted a direct-acting hoisting barrel similar to that employed in the steam warehouse hoist illustrated Fig. 106, Section 2. This hoist has a simple arrangement for obtaining either single or double purchase; it can be used for a variety of purposes, such as discharging ship's cargo into lighters or *vice versâ*, and is altogether a very valuable addition to a tug. On the forward side of the boiler is fixed a large water tank, one side of which is formed by a bulkhead; this tank can either be stored with fresh water for use in the tug's own boiler, which is much better than employing salt water, or it can be used for taking a supply of fresh water out to ships in need of it. Over the tank will be seen a direct-acting steam fire engine; this is a very important addition to the tug, as in case of a fire breaking out on the quay or in the harbour where the tug is usually employed, it can be immediately used as a floating fire engine. The pump is also used for pumping fresh water into ships. The arrangement of the towing gear is so clearly shown on the engraving that it needs no special description. All the pipes connecting the engine and boiler, &c., are of copper, and the whole is of the best workmanship and materials throughout.

The tug referred to was designed and supplied by the Authors for use on the coast of Africa, and it has rendered good service under the conditions above referred to. Everything was fitted together in place, and marked for re-erection at destination, but it was sent out in pieces, which effected a large saving in freight; the sides of the hull were painted different colours, and the plates and ribs being distinctly marked, the work of erection was completed very quickly, and at little cost, by men who had not previously been employed in work of that character.

STEAM LAUNCHES. The large number of steam launches and small yachts now in use for business and pleasure in all parts of the world, has naturally led to the production of very superior boats; and steam yachts are now made capable of attaining a speed of over 20 miles an hour. Fig. 29 is merely an illustration of one type much adopted, but there are many varieties, and the values necessarily vary with the character of the boat and fittings required. Many of the engines referred to in the foregoing pages are suitable for launches and yachts, especially the vertical engines and the three-cylinder engines, Figs. 25 and 30. The three-cylinder engine is very compact, and possesses the advantage of requiring but little attention, and working almost noiselessly. The subjoined price list gives the approximate cost of launches, but, owing to the many variations in style and detail, and the constant alteration in cost of production, the prices must be regarded as being only approximate.

The yachts tabulated are similar in appearance to the engraving.

PRICES, &C., OF STEAM LAUNCHES, Fig. 29.

Length	30′ 0″	35′ 0″	45′ 0″	50′ 0″	60′ 0″
Beam	6′ 0″	6′ 6″	7′ 0″	8′ 0″	9′ 0″
Approximate speed in miles per hour	11	12	13	14	15
Price clinch built of mahogany	£350	£440	£560	£680	£820
„ „ „ teak	£365	£455	£575	£700	£840
„ carve built of mahogany	£420	£490	£610	£730	£875
„ „ „ teak	£430	£500	£620	£740	£890
„ built of iron..	£445	£525	£645	£765	£910
„ „ steel	£455	£540	£660	£785	£935

These prices are for delivery in London; packing for shipment will vary according to circumstances, but will seldom exceed 5 per cent. The draught can be varied to suit requirements, averaging about 2 ft. 6 in. in the smaller sizes, and 3 ft. to 4 ft. in the larger ones.

THREE-CYLINDER STEAM ENGINE (Willan's patent), Fig. 30. *Engineering* says:—"The engine can be run at almost any speed without noise or inconvenience, whilst the distribution of steam effected is very good. For driving fans, centrifugal pumps, or similar high-speed machinery, this engine is exceedingly well adapted, while it might readily be arranged as a very handy wall engine for driving fast-running shafting."

The construction is such that the connecting-rods are always in compression, so that there

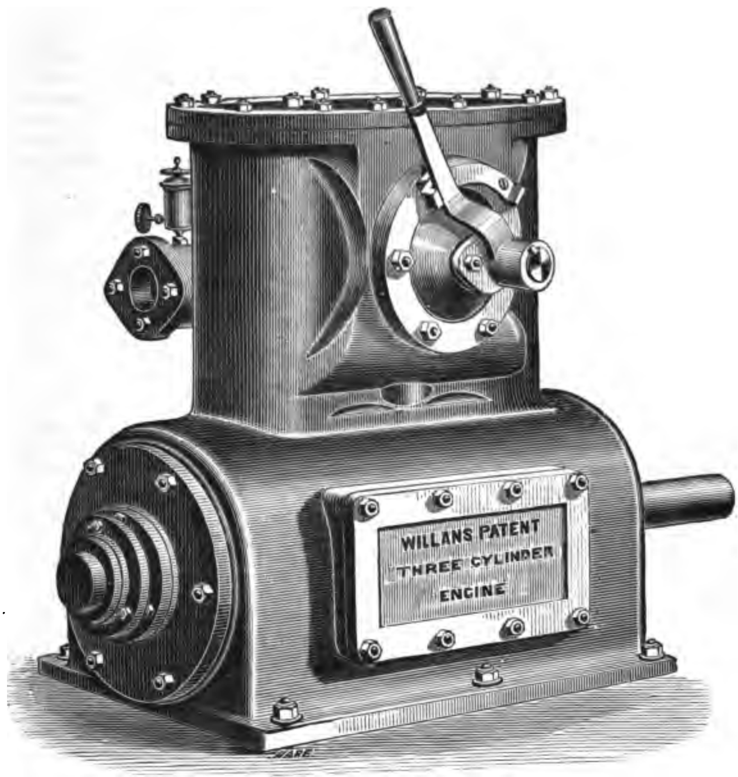


Fig. 30.

is no blow on the cranks, and there is an absence of "knocking," which is so often experienced with double-acting engines when running at high speeds. The small space occupied in height and width is an advantage on board a small steam yacht or tug-boat; there are few working parts, all well protected from dust, &c., and as there is no dead centre, a fly-wheel is not required, and it is not necessary to employ a skilled driver.

Indicated horse-power, with 70 lbs. steam per square in.	6	11	32	37	72	125
" " 30 lbs. " "	2½	4½	13	16	31	53
Diameter of cylinders	3"	4"	6"	7"	8"	10"
Length of stroke	4"	4"	6"	7"	9"	12"
Number of revolutions per minute	400	400	350	300	300	250
Weight of engine complete in cwt.	2½	3½	8	9	16½	31
Price complete with reversing gear	£25	35	55	80	110	180
Extra fitted with high-speed governor	£5	5 10	7	8 10	10	12
Diameter of steam pipe	¾"	1"	1½"	1¾"	2"	2½"
Diameter of exhaust pipe	1"	1½"	2"	2½"	3"	3½"
Breadth	12"	15"	20"	22"	27"	34"
Height	19"	20"	29"	40"	42"	50"
Length, over bearings	18"	25"	36"	47"	49"	60"

Packing and delivery 5 per cent. extra.

ATMOSPHERIC-GAS ENGINE (Otto and Langen's patent), Fig. 31. The first attempts to introduce gas engines were not followed by the success anticipated; this was probably owing to the manner in which it was tried to utilise the explosive energy of the gas. The engines employed were very similar in design to the ordinary horizontal steam engine. The gas introduced into the cylinder was exploded, a sudden blow was thus communicated to the crank shaft through the connecting-rod, which was attended with many disadvantages: a very large fly-wheel was required to absorb the power thus suddenly generated, and give it out uniformly; the various parts subjected to the blow soon got out of order, and the cylinder became foul from the tar, &c., which was left after the explosion. In the engine, Fig. 30, these difficulties have been very ingeniously overcome, and a saving in gas of more than 80 per cent. is effected. The action of this engine is as follows. Gas and air, mixed in such proportions as to give a mild explosive compound, are admitted under a piston which slides air-tight in a vertical cylinder open at the top; this compound is ignited, explodes, and drives the piston upwards. The ignited gases having increased in volume, lose their heat, their pressure becomes less as the piston rises, and when it reaches the top of its stroke, a partial vacuum is formed, and the pressure of the atmosphere causes the piston to descend. The work thus done steadily by the atmosphere during the return stroke of the piston yields the driving power, which is transferred to the shaft by suitable mechanism. This utilisation of the instantaneous power of the explosion by allowing the piston to fly up freely, without doing other work than emptying the cylinder of air, is the basis of the great economy and success of these engines. These gas engines possess many advantages over steam engines for many purposes where only a small power is required. They can be started at a moment's notice, and will at once give out their full power; no time is lost in getting up steam. When no longer required, they can be stopped without waste fuel. This is not the case with steam engines, for even if the fires be immediately drawn, there is still a large quantity of heat in the boiler which is wasted. The attendance required does not average more than about an hour per day for one man, and as there is no firing or stoking nor risk of boiler explosions, the principal fire insurance companies require no increase in the premiums on premises where these gas engines are erected. If less than the full power is required, the number of explosions (and consumption of gas) is reduced by self-acting mechanism in proportion to the reduced power wanted. Common coal gas (at 4s. per 1000 cubic ft.) will feed these engines for about one penny per hour per horse-power; in fact this is the guaranteed consumption, and if it is exceeded after a reasonable trial, and due care has been taken, the engines may be returned.

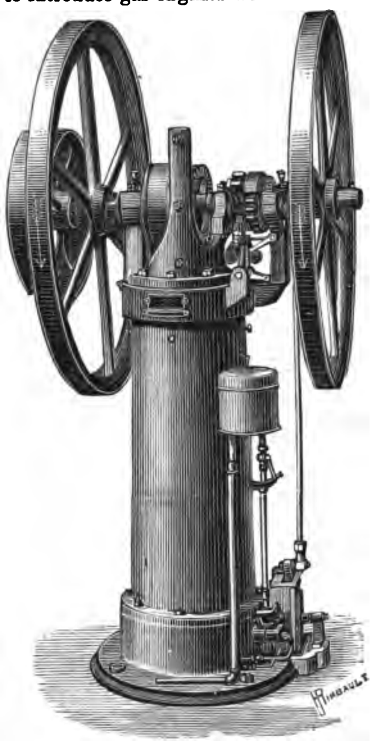


Fig. 31.

Horse-power		¼	½	1	2	3
Diameter of fly-wheel		34″	48″	48″	60″	60″
„ driving pulley		10″	12″	12″	27″	27″
Number of revolutions of fly-wheel per min.	at full power	100	95	95	95	95
„ strokes of piston „	at full power	40	36	32	30	30
Price of engine complete		£62	£80	£105	£144	£180
Weight of engine in cwt., packed		9	20	29	42	56

Packing and delivery 5 per cent. extra.

COMPRESSED-AIR ENGINES (see Section 5). The use of compressed air as a motive power has of late years largely increased, not only for a variety of purposes in underground workings, but also for driving tram-cars, working rock drills and other similar machines; in fact, in very long or deep workings, such as the Mont Cenis or St. Gothard tunnels, compressed air is perhaps indispensable for driving machinery, as instead of producing noxious

vapours and heat, like the steam engine, the exhaust assists materially in the often somewhat difficult task of ventilation. Although an ordinary steam engine may be driven by compressed air, much inconvenience is experienced from the air ports being clogged with ice, it being almost impossible to dry the air before using it. The Authors have designed and manufactured many air motors for use in tunnelling work which have given very satisfactory results. The supply valves are quite distinct from the exhaust valves, the latter being so placed that the exhaust air blows straight out from the cylinder without having to travel any sinuous ports; with this arrangement no inconvenience whatever is experienced. A motor of this form, constructed by the Authors, is illustrated in Spon's 'Dictionary of Engineering,' Figs. 2582 and 2583, pp. 1299 and 1300, where it is shown driving six diamond rock drills. The cost of compressed air motors is nearly the same as that of horizontal steam engines, Fig. 4, the prices for which will be found at p. 7, and Section 2, p. 114.

HEATED-AIR ENGINES. Although numerous attempts have been made to introduce hot-air engines, and many have been worked for considerable periods (Stirling's engines worked the Dundee foundry for many years, developing 45 horse-power), they have never hitherto given good commercial results in large sizes; but for small powers they compare favourably with small steam engines, at least in economy of fuel. Although more bulky, and consequently much higher in first cost than steam engines of equal power, it must not be overlooked that no boiler is required which reduces the total cost to near that of the engine and boiler together; when once started, they will run for hours without any attention, and owing to the low pressures generally employed, and the absence of boilers, there is no risk of explosion. In Wenham's patent engines, tabulated particulars of which are given below, the air is heated in a closed combustion chamber by direct contact with the fuel, and passes with the gases evolved into the cylinder. The cylinder is single acting, the upper part of it being arranged to serve as an air pump, and there is the usual regenerator for economising fuel.

PRICES, &C., OF WENHAM'S PATENT HEATED-AIR ENGINES.

Horse-power	½	1	2	3	5	10
Diameter of cylinder	12″	16″	20″	24″	30″	40″
Number of revolutions per minute	140	120	110	100	90	90
Price of engine complete	£75	£98	£144	£190	£277	£370

Packing for shipment about 5 per cent.

The following advantages are claimed for the Wenham engine:—

Economy of fuel and complete combustion of smoke.
It is self-contained, and portable, requiring no fixing or building of any kind.
The use of it does not increase insurance premiums.
The fire is charged only twice in one day's work; beyond this no attention except the occasional application of an anti-attrition powder, used in place of oil, is necessary.
No risk of explosion attends their use, the pressure never exceeding 15 lbs. per square inch.

RYDER'S HOT-AIR ENGINE, Fig. 32. The Ryder Compression or Hot-air Engine is for small powers, from half a horse to two horses. As will be seen from the sectional engraving, it is extremely simple in construction, there being no valves excepting a small check valve which supplies any trifling leaking of air which may occur. Like the Wenham engine, the attention of a skilled labourer is not required, but unlike it, none of the moving parts are exposed to the direct heat of the fire, and experiment has shown that it will develope as much power with a given weight of coal as any of the small motors. It will be seen on reference to Fig. 32, that the engine consists of a compression cylinder, A, and a power cylinder, B, with their respective plungers, C and D, and a regenerator, H. The lower portion of the compression cylinder is kept cool by the water circulating in the vessel E, whilst the lower portion of the power cylinder is kept hot by the action of the fire on the heater F. The compression plunger C nearly reaches the base of the engine, but is a trifle smaller than the interior of the cooler E, leaving a thin space for the air to pass down and become thoroughly cooled. The power piston is also of sufficient length to nearly touch the heater F at the lower part of its stroke, and both it and the heater are so formed as to present a small annulus of air to the action of the fire so that it may be very rapidly heated. The telescope or quill G forms a small annular passage for the air to pass down on its way from the compression cylinder to the power cylinder. Between the cylinders is situated the regenerator H, which is composed of a number of thin metal plates slightly thickened at their edges, which, while affording a free passage to the air, subdivides it into thin sheets; thus a large portion of the heat is alternately abstracted from and returned to the air in its passage to and from the power cylinder, producing great economy in fuel and steadiness of power in the engine. As the same air is

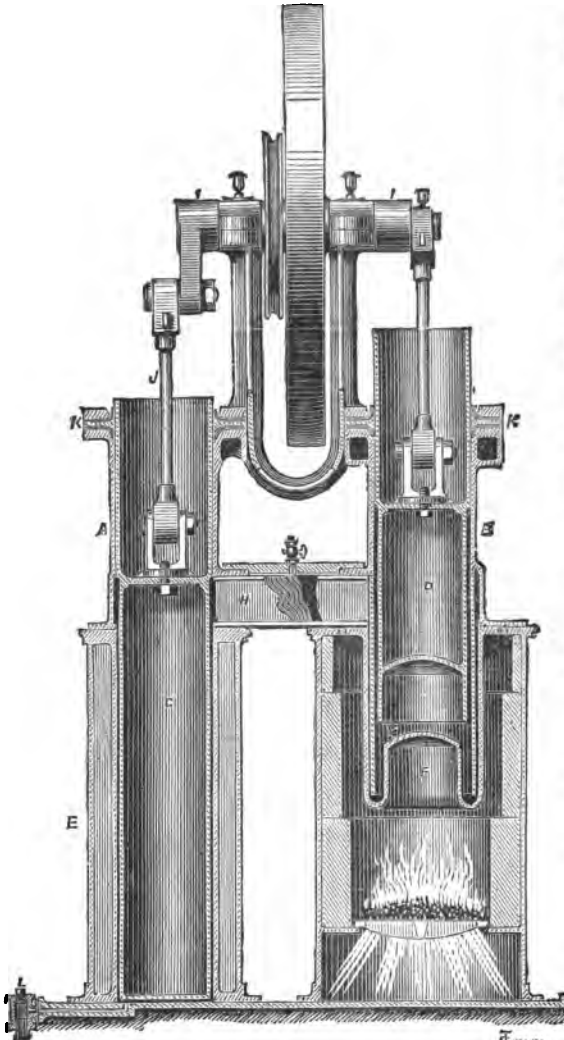


Fig. 32.

continually used, there is no noise occasioned by the escape of exhaust air.

A certain amount of water must either be pumped through the cooler E or allowed to circulate through it by gravitation to keep it cool, and it must be evident that the most economical adaptation of this machine is as a pumping engine; when so employed, all the water pumped is made to pass through the cooler on its way to the tank or other destination.

The hot-air engine will undoubtedly be extensively used for a great variety of purposes when it becomes more known that it is perfectly safe and very economical. Little or no skilled labour is required to keep it in good working order, and the firing is practically the same as for an ordinary stove.

For factories where a motor is required to work sewing or other small machines, nothing better could be desired.

It is also remarkably well adapted for pumping water into a tank on the top of a warehouse or other building to supply the hydraulic power required to work a lift of the construction illustrated and described at pp. 98 and 99, Section 2. The engine is kept in motion as long as may be necessary, and the water being used over and over again, there is little waste. This arrangement is far more economical than taking the water from the public mains, even where this can be done at a low tariff.

The price of these engines fitted for pumping is the same as when intended for driving sewing machines, coffee mills, printing machines, &c. &c., and is given below :—

Nominal horse-power	½	1
Diameter of cylinder	6″	10″
Number of revolutions per minute	120	100
Price, complete as shown	£45	£75
Height to top of fly-wheel	5′ 8″	7′ 6″
Floor space required	2′ 4″ × 3′ 3″	2′ 8″ × 4′ 4″
Weight in lbs.	1200	2600

Extra on list price for packing and delivery in London, 5 per cent.

WINDMILLS have been and still are extensively used in many parts of the world, but the extremely variable and unreliable nature of the power of the wind in this country naturally limits their application; for although, when once set to work, a windmill requires but very little attention, it is generally preferable to employ a more expensive form of motive power which can be relied upon for use whenever required. Still there are many cases, such as for grinding on a small scale, pumping for irrigation or drainage, &c., where windmills can be used with advantage, and in some parts of the world, where the force of the wind is pretty constant during a considerable portion of the year, they may be employed for almost any purpose, and with careful management would probably yield a good return. The cost of a windmill with wrought-iron tower and all modern appliances for reefing sails, &c., of about one horse-power with a fair breeze, is £120; but it is impossible to give data as to cost without full details of the local conditions.

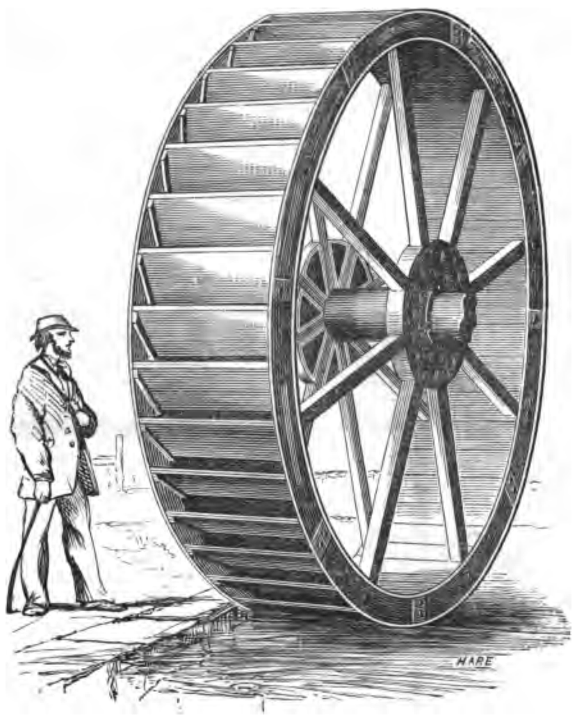


Fig. 33.

WATER-WHEEL, Fig. 33. There is, perhaps, no better agent for utilising water-power, where the supply is constant, and the pressure (or, what is equivalent, the fall) is low, than the water-wheel. There are several varieties, but those most generally used are the overshot, breast, and undershot.

The series of experiments conducted by M. Poncelet and M. Morin show that overshot wheels yield 60 to 80 per cent. of the theoretical power; breast wheels yield 45 to 50 per cent. of the theoretical power; undershot wheels yield 27 to 30 per cent. of the theoretical power. Notwithstanding the manifest loss in the power which ought theoretically to be developed, the undershot wheel is still very much used, partly, no doubt, because, as in floating mills, which are moored in rivers with a stream running from two to seven miles per hour, the motive power costs nothing more than the interest on the capital expended on the barge or craft and the water-wheels, and partly because water carriage was, and still is, in some countries practically the only cheap means of conveyance.

Mills of the kind last referred to may be seen in all parts of Europe, many of them of very ancient date, but probably few have been constructed within the last twenty-five years, steam mills and railway communication having superseded the slower and cheaper water ways and

mills. There are, however, localities where, as in Upper Egypt, fuel is scarce, and the water supply (the Nile) affords a motive power at once cheap and reliable, and where water-mills may be used with great advantage. A number of floating mills, with undershot wheels, have been designed and supplied by the Authors for use, under the conditions above named, and the cost of a pair of wheels 25 ft. diameter by 10 ft. wide, two pairs of stones, 4 ft. diameter, with complete dressing apparatus, and centrifugal pumps for utilising the power of the wheels for irrigation when the mill was standing, was £1200, the craft and housing being provided at destination.

This subject will be referred to in Section 6; but the data given above may be useful, and is, perhaps, as much as is necessary relative to machinery which must be specially designed to meet local conditions, which are constantly varying.

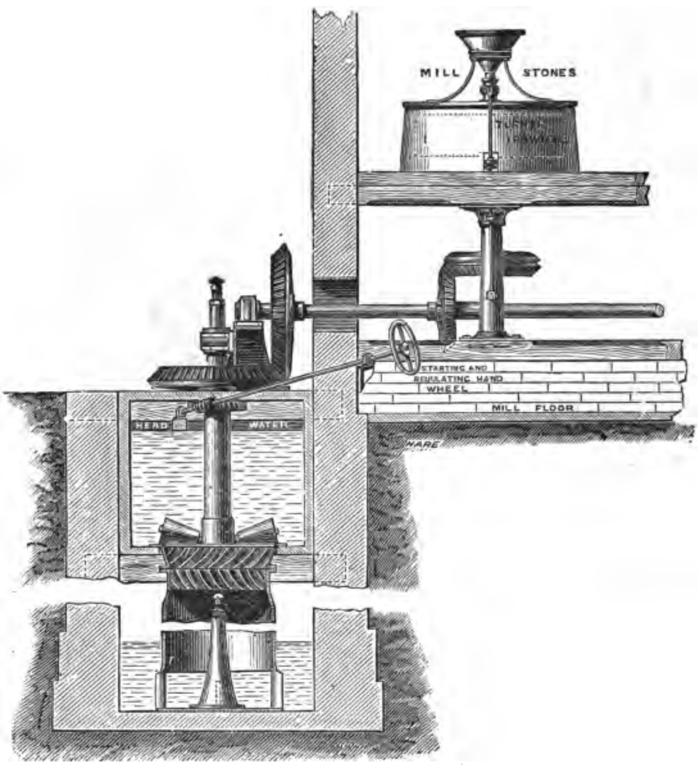


Fig. 34.

JONVAL TURBINE, Fig. 34, is adapted for low falls, and is available for driving a set of millstones or any other class of machinery. The price of turbines necessarily depends entirely upon attendant conditions, referred to at pages 47 and 48.

Where a plentiful supply of water is obtainable, turbines are undoubtedly a very excellent form of prime mover; after the first outlay but little expense is incurred for working or repairs, and it has been demonstrated beyond doubt that they give a much higher percentage of duty than a water-wheel.

One of the best examples of the employment of turbines is at Saint-Maur, where four Turbines, each of 120 horse-power, designed by the late M. Girard, the celebrated hydraulic engineer, may be seen at work supplying water to the city of Paris; but many equally good examples may be seen in Switzerland, Sweden, and Norway, where, practically, an unlimited supply of water, with a high fall, provides motive power at a very low cost, indeed so cheaply that manufacturers compete successfully with others far more favourably placed as regards the cost of land carriage for the raw material and finished products.

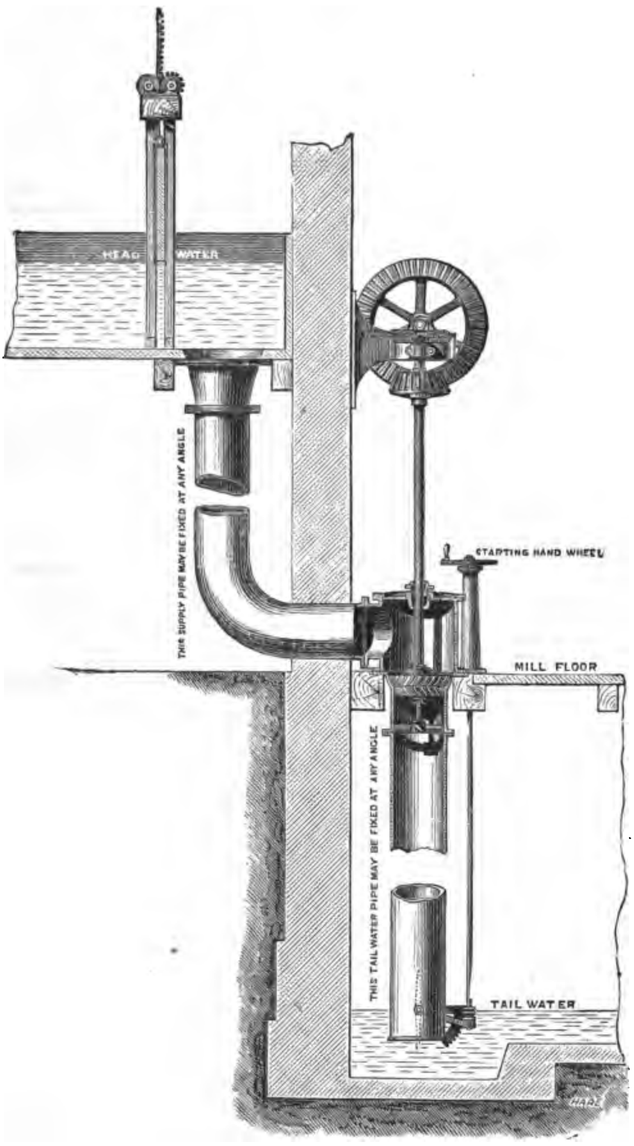


Fig. 35.

JONVAL TURBINE, Fig. 35. The water acts perpendicularly or parallel with the vertical driving shaft, directed through an annular ring of guide blades, set at the required angle, and impinging against a series of vanes fixed at an opposite angle on the circumference of the revolving wheel: the power is regulated by partially closing the water passages through the guide blades. Fig. 35 represents one of these turbines as erected and adapted for medium or high falls.

The subjoined list gives a general idea of the cost of the turbines, Figs. 36 and 37: but the power required and the height of fall available are so varied, that modifications of con-

struction and arrangement are often necessary. It is, therefore, impossible to compile a Table sufficiently comprehensive to be universally applicable. The prices given for the several parts will, in common with all other prices in this book, vary with the fluctuations in the cost of materials and labour.

Horse-power.	Height of fall in feet.	Cubic feet of water used per minute.	Revolutions of wheel per minute.	Cost of turbine.	Extra cost of movable guide blades.	Size of pipe in inches.	Cost of pipes per foot.	Approximate weight of turbine in cwts.
				£ s.	£ s.		£ s. d.	
6	15	282	247	65 0	17 0	16	0 17 0	28
6	20	212	341	57 0	16 0	14	0 14 6	24
6	25	169	446	50 10	14 10	13	0 12 6	22
6	30	141	567	47 0	13 10	12	0 11 0	18
6	40	106	811	44 0	11 10	10	0 8 6	16
6	50	85	1057	42 10	11 10	9	0 7 0	15
8	15	377	207	74 10	21 0	18	0 19 6	38
8	20	282	296	67 0	17 0	16	0 17 0	28½
8	25	226	391	60 0	16 0	14	0 14 6	25
8	30	188	491	55 0	15 0	13	0 12 6	23
8	40	141	700	49 10	13 10	12	0 11 0	18½
8	50	113	929	47 10	12 0	10	0 8 6	16½
10	15	471	185	86 0	24 0	21	1 8 0	50
10	20	353	264	75 0	20 0	18	0 19 6	38
10	25	282	350	68 0	17 0	16	0 17 0	29
10	30	235	439	62 10	16 0	14	0 14 6	26
10	40	176	630	58 0	15 0	13	0 12 6	24
10	50	141	830	55 10	14 0	12	0 11 0	22½
15	15	706	150	116 0	30 0	24	1 15 0	65
15	20	529	216	98 0	25 0	22	1 9 0	56
15	25	423	285	84 10	21 0	20	1 3 6	42
15	30	353	359	76 10	20 0	18	0 19 6	38
15	40	265	513	67 10	17 0	16	0 17 0	27
15	50	211	680	61 10	16 0	14	0 14 6	25
20	15	941	130	141 0	33 0	28	2 0 0	90
20	20	706	187	121 0	30 0	24	1 15 0	66
20	25	565	247	104 0	25 0	22	1 9 0	56
20	30	471	310	90 0	23 0	21	1 8 0	43
20	40	353	445	81 0	20 0	18	0 19 6	32
20	50	282	588	74 0	17 0	16	0 17 0	28
30	15	1412	105	184 0	40 0	33	2 11 0	130
30	20	1059	145	156 0	34 10	30	2 7 0	100
30	25	847	195	142 0	31 10	26	1 19 0	86
30	30	706	250	127 0	30 0	24	1 15 0	70
30	40	529	350	115 0	25 0	21	1 8 0	63
30	50	423	460	101 0	22 0	18	0 19 6	45

In this list each horse-power is equivalent to 33,000 lbs. raised one foot per minute; the fall is the distance between the water lines of the head and tail race. By a modification of the turbines the speed can be altered, but at a slightly-increased cost. The prices given for pipes are for 9-foot lengths with turned flanges, bolts, and joint rings; bends or short lengths are extra. When the pipes are long, and have to be laid in the ground, ordinary cast-iron socket-pipes can be used, and these can be obtained at a much lower cost; see Section 3. The outer cases of the turbines are of cast iron, the guide blades of wrought iron, and the revolving wheel, in the smaller sizes, of rolled brass; the larger sizes of wheels are made of wrought iron. The wheel is keyed upon a 4-foot length of shaft, for welding to any longer length required, and is fitted with pivot, pivot bridge, &c.

In order accurately to estimate the cost of turbines, it is necessary to know the quantity of water obtainable, or if this is not ascertained, the power required, assuming the water supply suitable; the total fall between the surface of the water in the head and tail races at the usual working levels; the length of pipe wanted (the water should be brought in an open cutting or timber trough, fitted with strainers, as far as convenient, so as to shorten the pipes); and particulars and speeds of shafts, and pulleys required. A rough sketch, giving proposed arrangement and position of turbine, is also very useful.

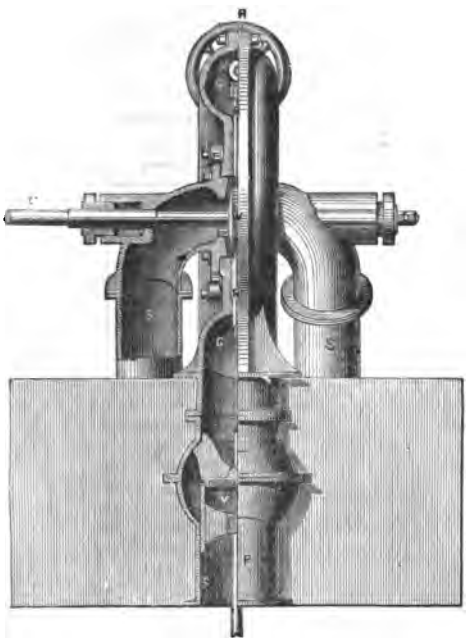


Fig. 36.

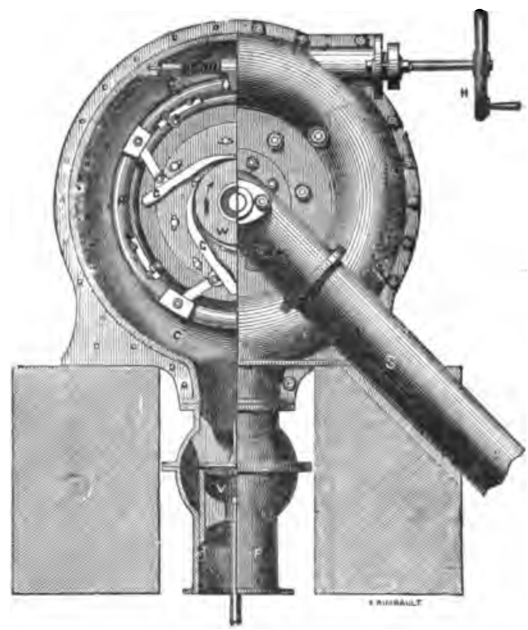


Fig. 37.

VERTICAL VORTEX TURBINE. Figs. 36 to 40 all represent various forms of the vortex turbine, invented by Professor James Thomson. The water is admitted at the circumference, and after it has expended nearly all its energy, it passes out at the centre; this is exactly the reverse of the action of the Fourneyron turbine. Professor Rankine, speaking of the vortex turbines, said :—" In every form of turbine a whirling motion is given to the particles of " water before they begin to drive the wheel, and the efficiency of the turbine depends on the " completeness with which that whirling motion is taken away from those particles during their " action upon the wheel. By discharging the water from a part of the wheel whose motion is " comparatively slow, the practical fulfilment of that condition is rendered more easy and " certain. The action of centrifugal force in regulating the speed is as follows. Should the " load be suddenly diminished, and the wheel begin to revolve too fast, the centrifugal force of " the water whirling along with it increases and opposes the entrance of water from the supply " chamber; on the other hand, should the load be suddenly increased, and the wheel begin to " revolve too slowly, the centrifugal force of the water whirling along with it diminishes, and " allows more water to enter from the supply chamber, and thus sudden variations of the load " are prevented from causing excessive fluctuations of speed, the whirling water acting as a " governor. In outward-flow turbines, the centrifugal force of the whirling water acts in the " contrary way and tends to increase the fluctuations of speed. In parallel-flow turbines, it has " no sensible action of either kind." These turbines can be arranged in such a manner as to admit of regulating the quantity of water passing through them, and in the list annexed the price includes adjustable guide blades, but in situations where a constant supply (of an invariable quantity) can be depended upon, the cost is considerably reduced by the adoption of fixed guide blades. The mode adopted for regulating the water supply is such that the passages are always smooth and of a continuous form, and are free from contractions, thus causing less waste of power than regulation by sluices or valves.

In Figs. 36 and 37, one-half of each view is in section showing the internal arrangements. The water enters through the pipe P into the annular chamber C, from whence it is conducted by four guide blades GG into the revolving wheel W, and is discharged at the centre. The two suction pipes, SS, convey it to the tail race. The revolving wheel W, is keyed

on the main driving shaft D; an equilibrium valve, V, is placed in the supply pipe for shutting off the water. The guide blades GG are hinged at their inner points, which enables their angle to be varied by a series of levers actuated by the hand wheel H. As mentioned before, this arrangement is only necessary when the power required varies considerably at different times, and saving water is an important consideration; but when the power required is constant the guide blades are made fixed. The wheel may be placed at any height less than 30 ft. above the tail race; and the fall rendered available by the suction pipes, as shown in the engraving, Fig. 38, illustrates the position in which this wheel is sometimes placed, a portion of the fall being obtained by cutting below the level of the mill floor. In this case suction pipes are not required. AA is the supply pipe, B the wheel, SS the driving shaft. A slide or sluice is provided for closing the mouth of the conduit D (which leads to the tail race) when it is required to examine or repair the wheel. The bearing-block of the toe step is usually formed of lignum vitæ, when it is for use under water, as in this engraving. Engravings Figs. 39 and 40 are perspective views of horizontal and vertical arrangements of the vortex turbine. The power from the horizontal turbine is taken by means of bevil-toothed wheels, whilst that from the vertical one is conveyed by a pulley and leather belting.

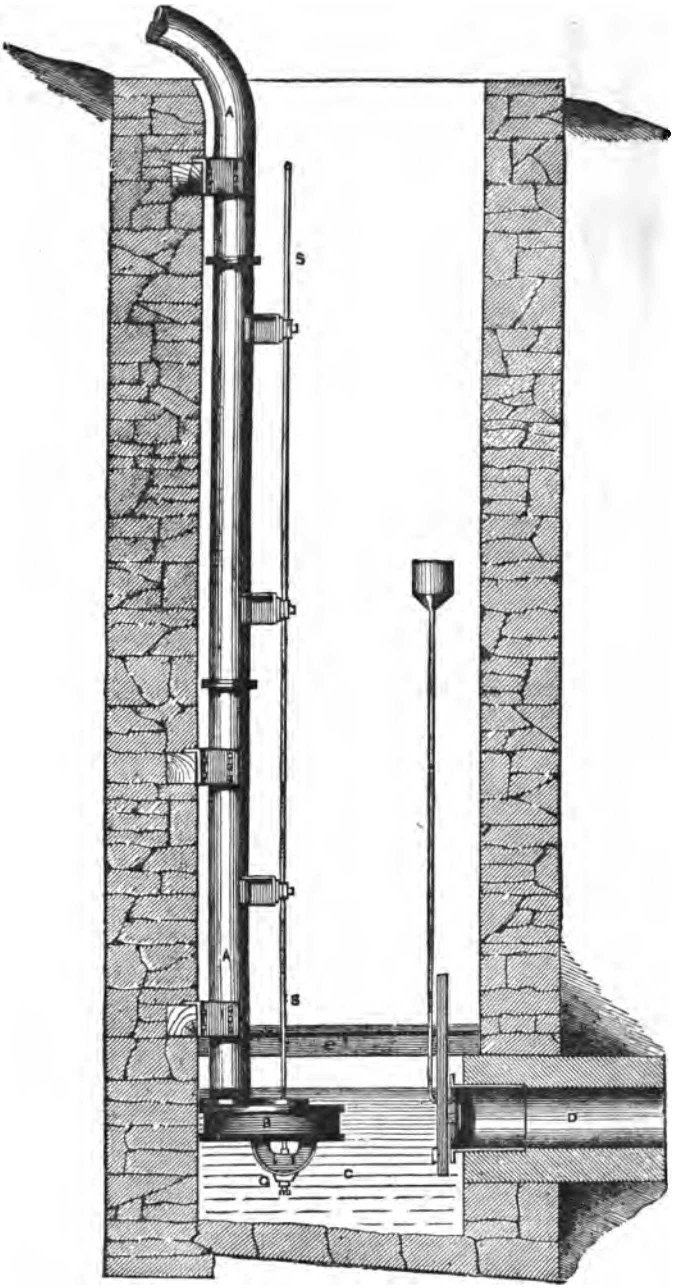


Fig. 38.

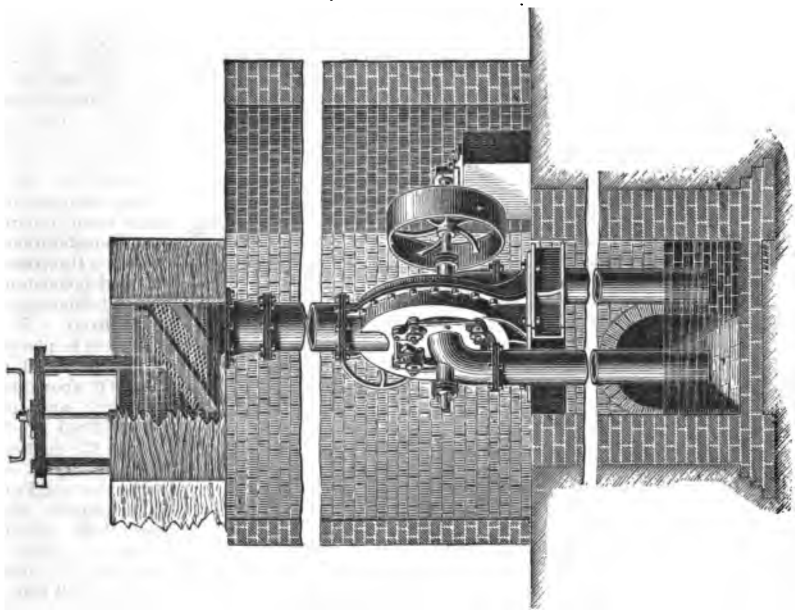


Fig. 39. *Vortex arranged vertically, with part of the fall acting by suction.*

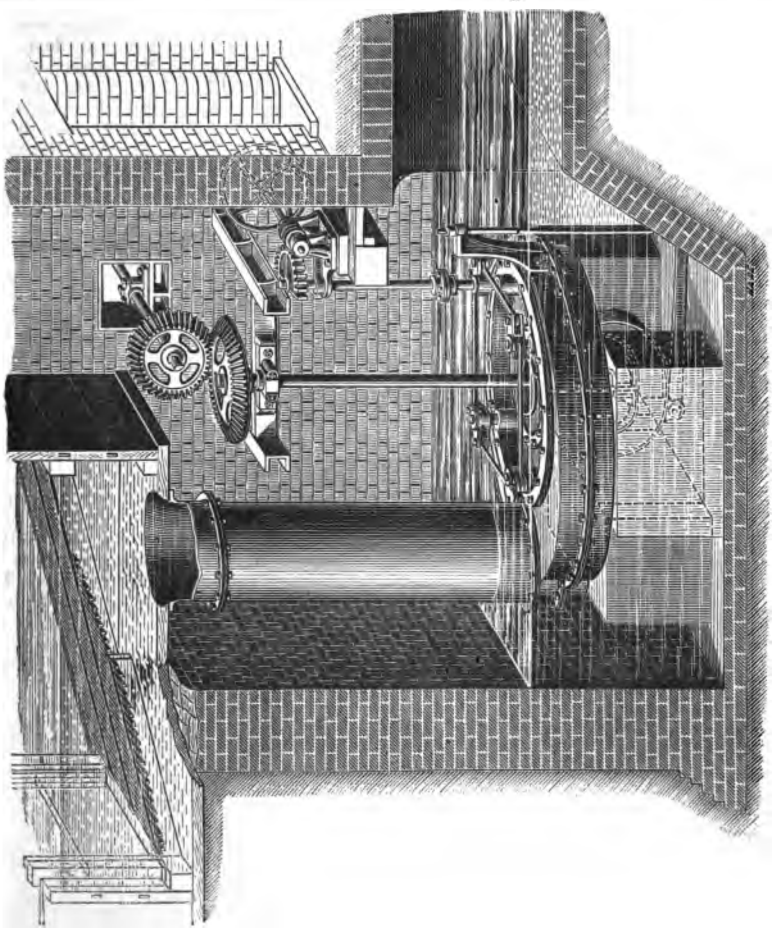


Fig. 40. *Vortex arranged horizontally at the bottom of the fall.*

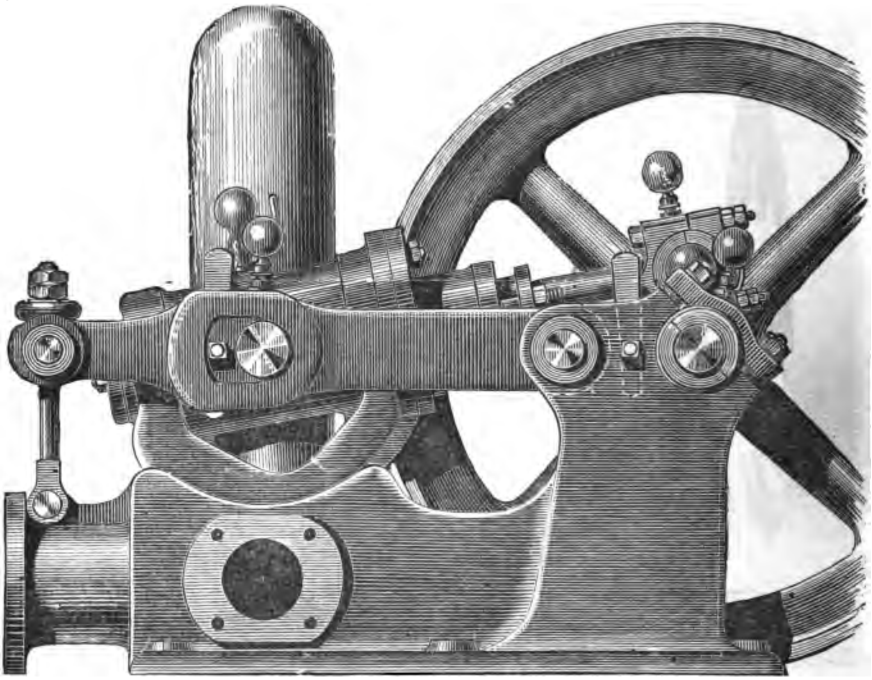


Fig. 41.

SCHMID'S PATENT WATER PRESSURE ENGINES, Fig. 41, show a form of motor which can be employed with any head of water, from 70 ft. to 300 ft. The cylinder is oscillating, the passages being formed on a curved face struck from the cylinder trunnions. This face works on a corresponding concave face formed in the bed plate, and these faces are kept water-tight by the mode of carrying the cylinder trunnions, which are hung in a pair of levers having their fulcra at one end near the crank-shaft bearings, and connected by a cross bar at the other end; a bolt passes through this cross bar, and gives the required downward pressure (which in practice is found to be very slight), and an indiarubber washer is inserted beneath the nuts on this bolt to admit of easy adjustment. An air vessel is provided on the supply pipe to absorb any shocks to which the engine might be subjected by sudden variations in the supply of water. These engines are simple, having few moving parts (and these not liable to get out of order), and it has been proved in a competitive trial that they gave a useful effect of 89 per cent.; they are designed for use with a high-pressure supply, and should not be used with less than 30 lbs. pressure per square inch.

It will easily be seen that, by reversing the action, this machine will form an excellent pump, the exhaust pipe then becoming the suction and the supply the delivery pipe.

The subjoined list gives the powers developed at various heads.

PRICES, &c., OF SCHMID'S WATER ENGINE.

Diameter of cylinder	1½"	2"	2½"	3"	4"	5"	6"	7"	8"	9"	10"
Stroke of „	2"	2½"	3⅛"	3¾"	5"	6¼"	7½"	9"	10"	11½"	12½"
Number of revolutions per min.	300	276	230	200	156	130	112	100	96	90	86
Gallons of water used per hour	460	939	1524	2274	4200	6900	10260	15000	20922	30080	36780
„ „ discharged as a pump	384	845	1370	2046	3780	6210	9234	13500	18829	27027	33102
Horse power for a head of 50 ft.	..	..	..	·45	·85	1·3	2	3	4·2	5·6	7·4
„ „ „ 100 „	..	..	·6	·9	1·7	2·7	4	6	8·4	11.3	14·8
„ „ „ 150 „	..	·57	·9	1·3	2·5	4	6	9	12·6	17	22·25
„ „ „ 200 „	·35	·75	1·2	1·8	3·4	5·5	8	12	16·8	22·7	29·7
„ „ „ 250 „	·43	·95	1·5	2·25	4·25	6·9	10	15	21	28·4	34
„ „ „ 300 „	·5	1·1	1·8	2·7	5	8·3	12	18	25	37	44·5
Price complete	£10	£14	£18	£26	£34	£44	£54	£65	£76	£95	£120

Packing and delivery about 5 per cent.

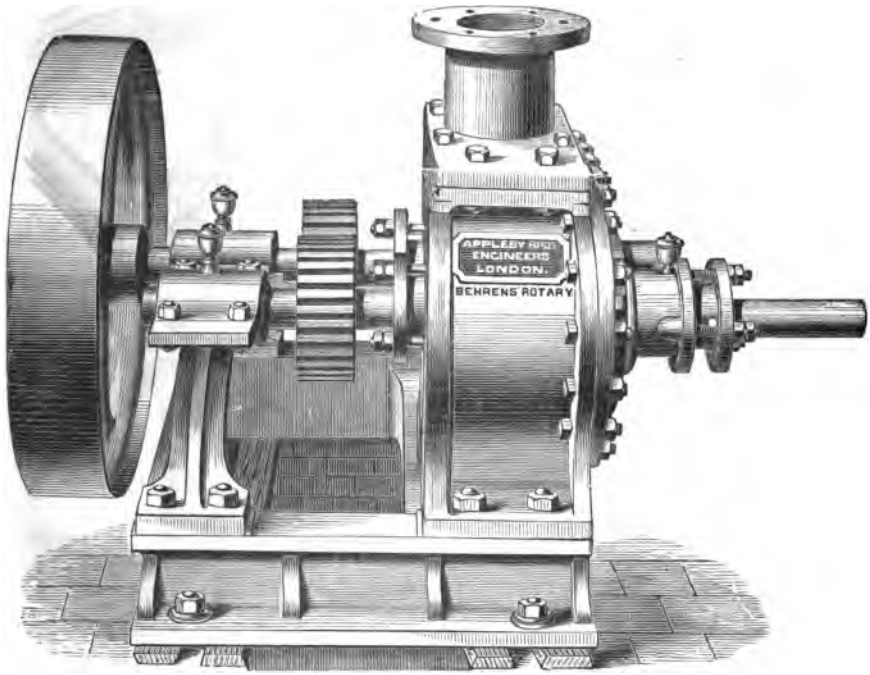


Fig. 42.

BEHREN'S ROTARY WATER ENGINE, Fig. 42, is an extremely simple form of water motor with very few moving parts, and these not liable to much wear. It consists of a casing bored out to receive two piston blocks, which give an alternate abutment to each other. The pistons are connected by spur wheels, the motion of the pistons is therefore perfectly uniform and continuous in one direction, and no power is lost in overcoming the inertia of reciprocating parts, as in the ordinary engine, and a heavy fly-wheel is not required. Pumps are constructed on a similar principle. See Section 3.

PRICES, &c., OF BEHREN'S PATENT ROTARY WATER ENGINES, Fig. 42.

Diameter of piston	4"	6"	8"	10"	12"	15"
Width of piston	2½"	4"	5¼"	6⅝"	8"	10"
Number of revolutions per minute	573	382	286	229	191	152
„ gallons of water used per hour ..	3200	7700	14000	2 1400	38000	43000
Horse power obtained by a fall of 50 ft. ..	·7	1·75	2·8	4·2	7·5	9·5
„ „ „ 100 „ ..	1·4	3·5	5·7	8·5	15	19
„ „ „ 150 „ ..	2·25	5·3	8·5	12·75	22·5	28·5
„ „ „ 200 „ ..	3	7	11·5	17	30	38
„ „ „ 250 „ ..	3·75	9	14·2	21·5	37·5	47·5
„ „ „ 300 „ ..	4·5	10·7	17·4	25·5	45	57
Price	£23 5s.	£27	£44	£52	£81	£126

THREE-CYLINDER WATER ENGINES, Fig. 43. This kind of engine has been employed for a great variety of purposes with very good results, and, like the engines referred to in the preceding pages, it possesses many advantages over the steam engine where water power is available.

It occupies less space, requires but little attention, and there is no risk of fire and consequent increase in the rate of insurance premium, no delay is caused by having to get up steam, the full power of the engine may be obtained at a moment's notice, and there is nothing corresponding to the loss of fuel, which is sustained when the steam engine is no longer required, and the fire has to be drawn. These motors are not recommended for use with less pressure than 25 lbs. per square inch, but they will work at any pressure up to 700 lbs. per square inch, and are suitable for use in mines for driving drums, capstans, opening and closing lock gates, &c. With pressures below 25 lbs., more economical results will be obtained from a turbine or water wheel.

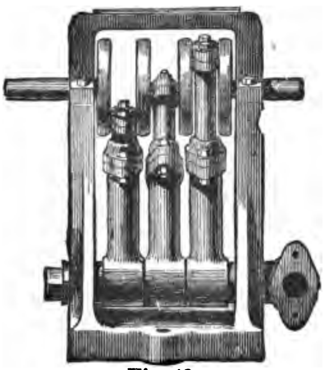


Fig. 43.

The engine, Fig. 43, consists of three vibrating cylinders working on a hollow trunnion in which are formed the necessary inlet and outlet ports. The three plungers with bearings at one end, act upon the crank pins in turn, thus causing the crank shaft to rotate. The whole is carried in a neat cast-iron frame, and may be easily fixed to a timber or other suitable foundation.

PRICES, &c., OF 3 CYLINDER WATER ENGINES, Fig. 43.

Diameter of cylinder	2"	2½"	3"	3½"
Length of stroke "	5	5	6	9
Number of revolutions per minute	50	50	50	50
Number of gallons of water used per minute.. ..	487	812	1565	2777
Horse-power with a pressure of 100 lbs.	½	1	1½	3
Approximate weight in cwts.	2½	3	4	7
" measurement in cubic ft.	5	6	7½	15
Price	£16 10	£22	£30	£40

Packing for shipment and carriage about 5 per cent.

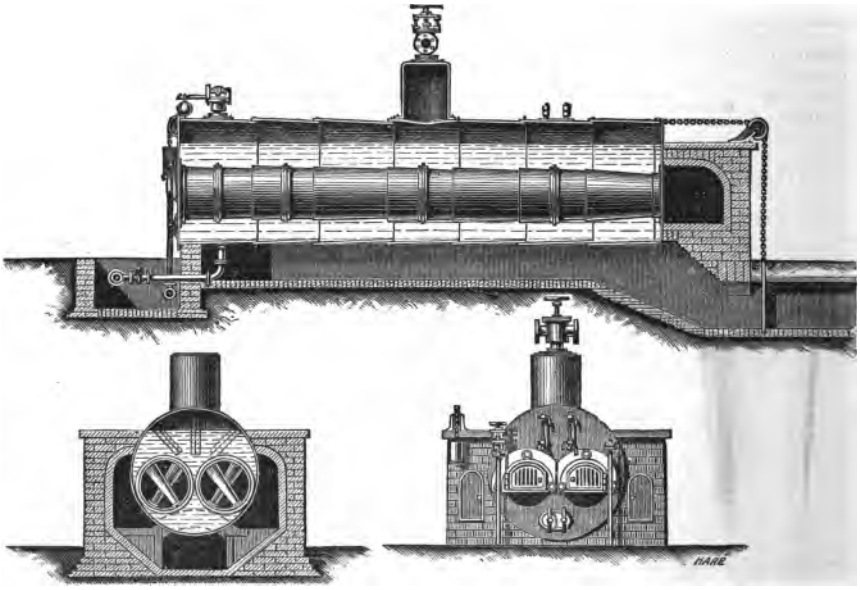


Fig. 44.

LANCASHIRE BOILER, Fig. 44, and **CORNISH BOILER**, Fig. 46. The Lancashire boiler has two flues which converge into a combustion chamber, whilst the Cornish boiler, Fig. 46, has usually one flue or tube, and to that extent the latter may be considered a more simple construction than the former, but the Lancashire boiler has some advantages, especially where great power is required. In large boilers the two flue tubes form good stays for the flat ends; the fire grates can be made of the proportions which give the greatest economy (very large grate surfaces having been proved to be less economical than those of moderate dimensions). If the flues are stoked alternately a more even temperature is maintained, the heat in one furnace is always at its highest when the other is at its lowest, and the two flues converging into one combustion chamber, it follows that the gases from the hottest furnace ignite and consume the thick smoke from the other which is being stoked, so that no unconsumed products ought to escape from the chimney in the form of black smoke.

A range of large boilers are often fitted with lifting bridges, a tube connecting the two furnaces in the front, and after a furnace has been newly fired, the bridge is lifted by a lever in the front of the boiler, and the whole of the smoke is made to pass over the other furnace. In all large works there is at least *one* boiler more than is necessary for daily use, so that any of the boilers may be laid off for periodical examination and repair when it is required.

The quality of material is usually best Staffordshire plates throughout, excepting in the tube over the furnace, the plates there being Low Moor, Farnley, or other approved quality, and each boiler is tested by hydraulic pressure to about twice its working pressure.

DIMENSIONS AND PRICES OF LANCASHIRE BOILERS, Fig. 44.

Nominal horse-power	20	25	30	35	40
Length	22′ 0″	25′ 0″	28′ 0″	30′ 0″	35′ 0″
Diameter	6′ 0″	6′ 3″	6′ 6″	7′ 0″	7′ 0″
Diameter of each flue	2′ 3″	2′ 4″	2′ 6″	2′ 9″	2′ 9″
Diameter of dome	2′ 6″	2′ 9″	3′ 0″	3′ 0″	3′ 0″
Height of dome	3′ 0″	3′ 0″	3′ 3″	3′ 6″	3′ 6″
Price of boiler	£185	£210	£255	£320	£420
„ „ with mountings	£220	£250	£300	£375	£480
Approximate weight in tons	8¼	9½	11	14	17½
„ measurement in cubic ft.	1100	1350	1750	2000	2400

DIMENSIONS AND PRICES OF CORNISH BOILERS, Fig. 46.

Nominal horse-power ..	3	4	6	8	10	12	16	20	25	30
Length	8′ 6″	10′ 0″	10′ 0″	12′ 0″	14′ 0″	15′ 0″	20′ 0″	22′ 0″	25′ 0″	30′ 0″
Diameter	3′ 0″	3′ 3″	3′ 6″	4′ 0″	4′ 3″	4′ 9″	5′ 0″	5′ 3″	5′ 6″	6′ 0″
Diameter of flue	1′ 6″	1′ 8″	1′ 10″	2′ 0″	2′ 3″	2′ 6″	2′ 9″	3′ 0″	3′ 0″	3′ 0″
Diameter of dome	1′ 3″	1′ 6″	1′ 8″	2′ 0″	2′ 0″	2′ 0″	2′ 0″	2′ 3″	2′ 6″	2′ 9″
Height of dome	1′ 3″	1′ 6″	1′ 9″	2′ 3″	2′ 3″	2′ 3″	2′ 3″	2′ 6″	2′ 9″	3′ 0″
Price of boiler	£40	£50	£55	£65	£75	£85	£125	£155	£200	£250
„ „ with fittings ..	£55	£65	£70	£85	£100	£115	£160	£195	£245	£300
Approximate weight in cwt.	27	33	36	45	55	65	100	125	160	200
„ measurement in c. ft.	110	150	190	300	400	500	750	900	1450	1630

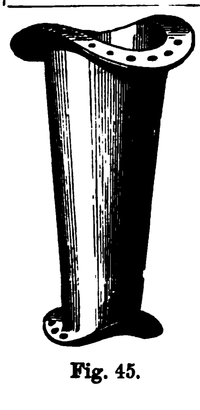


Fig. 45.

The **GALLOWAY TUBE**, Fig. 45, serves the double purpose of strengthening the flue, and increasing both the rapidity of circulation and the heating surface. The diameter of the tube just under the top flange being greater than the diameter of the other end, induces the more rapid circulation of the water and at the same time renders them easy of application to existing boilers. The prices of the tubes are as follows:—

Not exceeding	2′ 6″ long,	£1 15 0	each.
„	3′ 0″ „	£2 0 0	„
„	3′ 6″ „	£2 5 0	„
„	4′ 0″ „	£2 10 0	„

The cost of tubes with rivet-holes punched is 2*s*. per tube extra.

The exact internal and external diameter of the flue to be fitted, and the number of tubes, or the length of the flue, and a sketch showing the length of each plate in the flue, should be furnished when tubes are required to be fitted to an existing boiler.

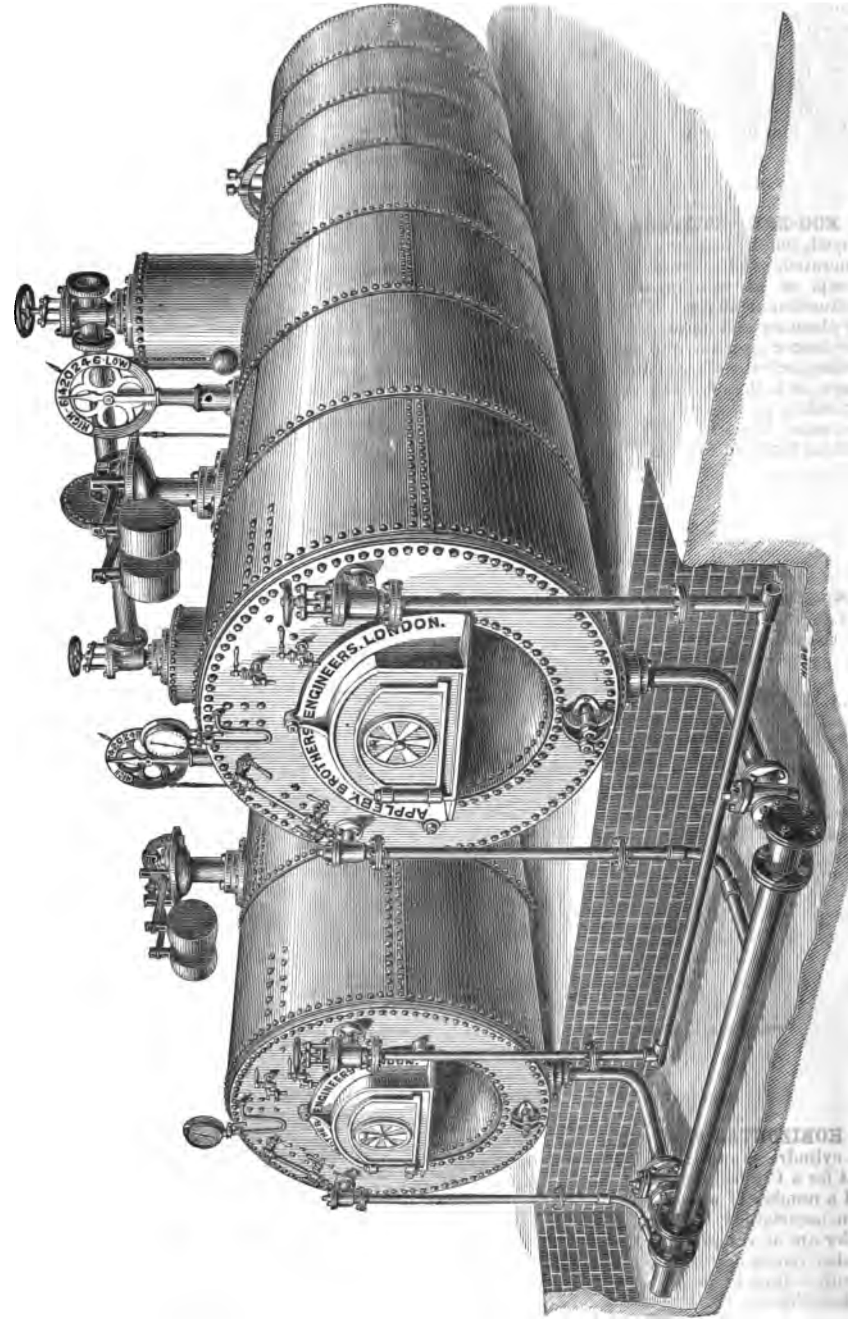


Fig. 46.

The **BOILER FITTINGS** are clearly shown in Fig. 46, which represents two of a range of Cornish boilers built for the locomotive shops of one of the Indian state railways. The mountings are such as are usually supplied by the Authors, and are of the kind recommended by the boiler insurance societies. They consist of furnace front with ventilator, grate bars, bearers, dead plate and damper, man-hole and mud-hole with cover and bridge, stop valve, safety valve, feed valve, gauge cocks, glass water gauge, Bourdon's or other steam-pressure gauge, blow-off cock, and fusible plug in the crown of each tube. These boilers were also fitted with a high and low water indicator.

EGG-END BOILERS. The egg-end boiler is undoubtedly the simplest form now employed, but it is by no means economical in consumption of fuel in proportion to the steam generated, and should only be used where the water is foul, or where fuel is extremely cheap, or at iron or other works where the heat from furnaces can be utilised for the production of steam. Under such conditions the low first cost of egg-end boilers, the facility for cleaning and consequent long life are good reasons in favour of their adoption. Boilers of the larger sizes have the longitudinal seams double rivetted, and they are usually made with semispherical ends, but dished ends can be used if the larger sizes have longitudinal or gusset stays, or both. No domes are included in the list price, but these will be added, or any other alteration in detail if desired. The cost of fittings will not vary much from those given for the same horse-powers for Cornish boilers; the separate cost of any single fitting or mounting will be found in Section 7.

PRICES, &C., OF EGG-END BOILERS.

Nominal horse-power	3	4	6	7	8	9	12	16	20
Length	10′ 0″	11′ 0″	14′ 0″	14′ 0″	16′ 0	20′ 0″	24′ 0″	28′ 0″	28′ 0″
Diameter	3′ 0″	3′ 0″	3′ 6″	4′ 0″	40′ 0″	4′ 0″	4′ 0″	4′ 6″	5′ 9″
Approximate weight in cwt. ..	22	25	30	35	40	50	60	75	100
„ measurement in c. ft.	90	100	175	225	260	320	390	570	1000
Price of boiler (without dome) ..	£25	£28	£35	£40	£45	£55	£70	£85	£110

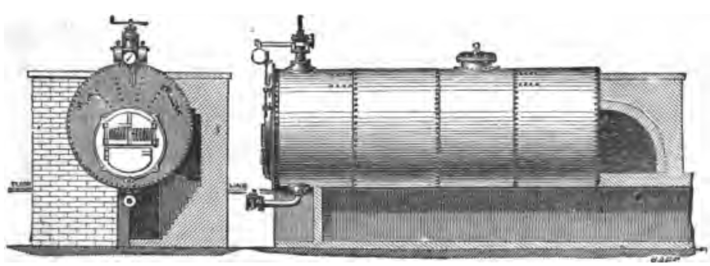


Fig. 47.

HORIZONTAL SEMI-MULTITUBULAR BOILER, Fig. 47. The outer shell and internal flue are cylindrical and the ends flat; the front part of the flue is arranged with a fire-grate, like that for a Cornish boiler, a tube plate is fixed in the flue at a short distance behind the furnace, and a number of wrought-iron (or brass) tubes pass from this to the back of the boiler. It has been ascertained by experiment that the first few inches of the tubes in any multitubular boiler are as valuable for the production of steam as the whole of the remainder, and when it is also remembered that the longer the tubes, the greater the difficulty in maintaining the required draught, it will be easily realised that the comparative shortness of the tubes in the boiler (Fig. 47) is by no means a defect, but that very economical results may be obtained from its employment.

PRICES, &c., OF PATENT HORIZONTAL SEMI-MULTITUBULAR BOILERS, Fig. 47.

Nominal horse-power	6	8	10	2	14	16	20	25	30
Length	10′ 0″	13′ 0″	14′ 6″	14′ 8½″	17′ 0″	19′ 0″	22′ 0″	25′ 0″	26′ 6″
Diameter	4′ 3″	4′ 4″	4′ 8″	5′ 3″	5′ 3″	5′ 8″	6′ 2″	6′ 4″	6′ 6″
„ of flue ..	2′ 4″	2′ 5″	2′ 8″	2′ 10′	3′ 0″	3′ 2″	3′ 6″	3′ 6″	2–2′ 6″
„ of tubes ..	2¾″	2¾″	2¾″	2¾″	2¾″	2¾″	2¾″	2¾″	2¾″
Number of tubes ..	24	28	34	38	43	48	50	60	70
Price of boiler	£85	£109	£125	£152	£172	£197	£247	£3[illegible]3	£363
„ and fittings	£100	£126	£147	£174	£200	£226	£279	£336	£400
Approximate measurement in cubic ft. ..	180	245	320	410	470	630	850	1000	1120

The fittings include wrought-iron man hole and suitable cover planed on their surfaces, furnace front and fire door, dead plate, bearer bars and bracket, bridge, furnace bars, double safety valve and stop valve, internal collecting pipe, glass water gauge, two gauge cocks, patent steam-pressure gauge and gun-metal gland blow-off cock with suitable elbow and fixing.

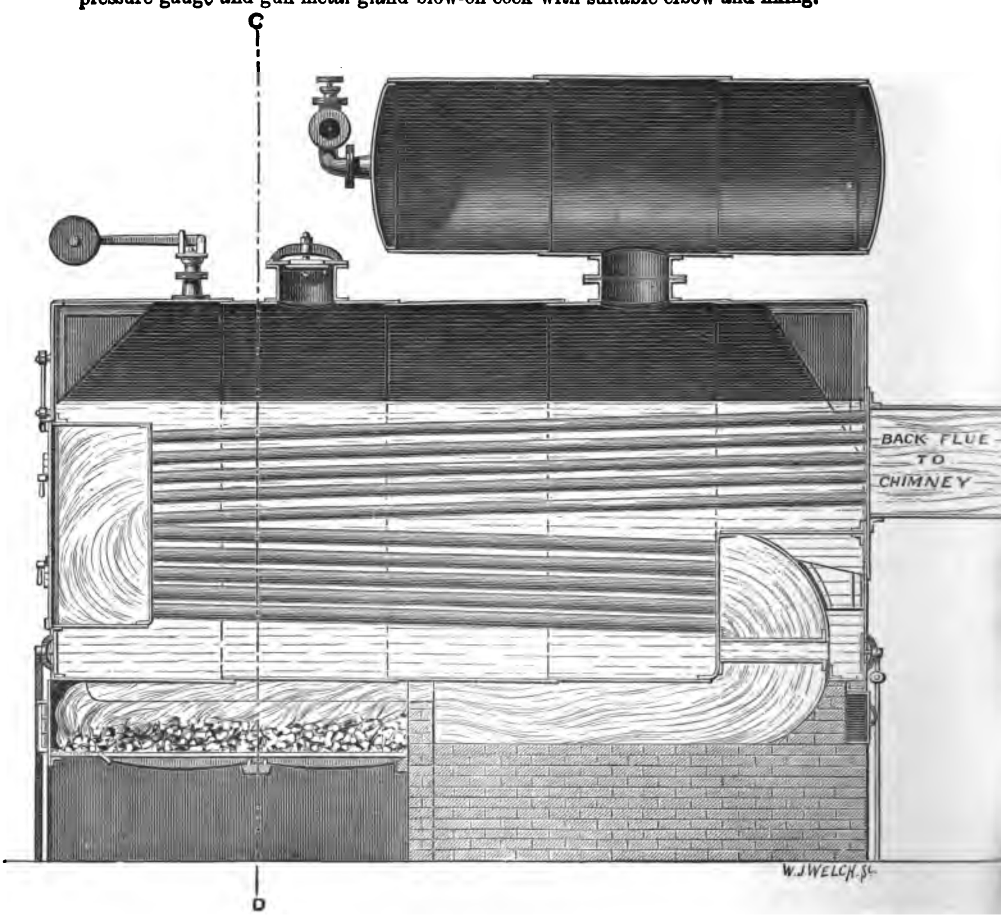


Fig. 48.

PATENT MULTITUBULAR BOILER. Figs. 48 and 49 give a longitudinal and cross section and end elevation of a class of fixed multitubular boiler which give highly economical

results. In a careful set of experiments made by Mr. T. Box on a 40 horse-power boiler of this type, it was found that 1 lb. of Welsh coal evaporated 11·8 lbs. of water; 1 lb. of Newcastle coal 10 lbs., and that inferior coal evaporated 8·4 times its weight of water. The fire grate is independent of the boiler, and can readily be enlarged to burn sawdust or other refuse, and for this reason many of these boilers are employed by saw-mill proprietors, &c. They occupy only a third of the floor space required by Lancashire boilers of equal power, and the arrangement is such that they are easily cleaned; and their durability is remarkable, many

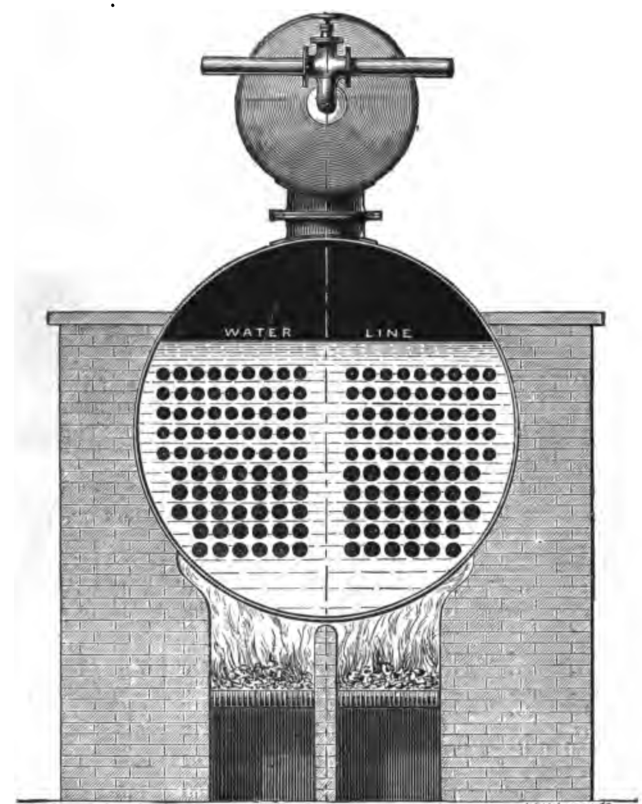


Fig. 49. *Cross Section.*

having been worked for upwards of ten years without requiring any repairs. Small bulk is often a feature of much importance, especially when boilers are required for shipment and transport by land. Their safety in use is proved by the fact, that, although some hundreds are at work, not a single accident has yet occurred. The cost is somewhat greater than that of the boilers previously referred to, but it must not be forgotten that they occupy less space, and that less brickwork is required for setting.

PRICES, &c., OF PATENT MULTITUBULAR BOILER, Figs. 48 and 49.

Horse-power	12	16	20	25	30	40	50	60	80	100
Diameter	4′ 6″	5′ 0″	5′ 6″	5′ 6″	6′ 0″	6′ 6″	7′ 0″	7′ 0″	7″6″	8′ 0″
Length	8′ 0″	8′ 0″	10′ 0″	11′ 0″	12′ 0″	13′ 0″	14′ 0″	15′ 0″	16′ 0″	17′ 0″
Price of boiler and fittings ..	£185	£245	£285	£315	£360	£445	£520	£580	£650	830

The fittings, &c., included in the preceding prices are man hole and mud hole, covers and bridges, cast-iron furnace front and doors with wrought-iron stays to build into brickwork, cast-

iron dead plate, bearer, and furnace bars, back soot door, straight smoke box (3 ft. long) to lead into chimney flue fitted with soot door and damper with weight and chain, also double safety valve, stop valve, water gauge, gauge glasses, gauge cocks, feed valve, blow-off valve, and patent steam-pressure gauge.

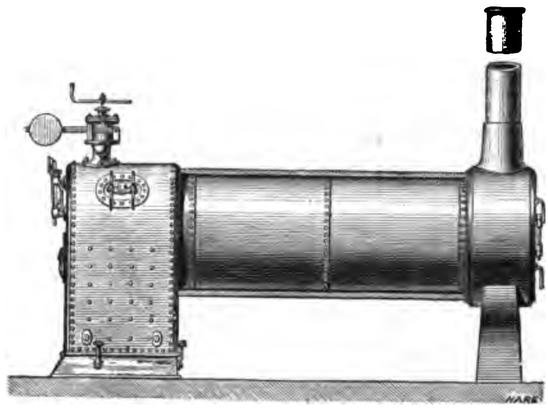


Fig. 50.

LOCOMOTIVE MULTITUBULAR BOILER, Fig. 50. This class of boiler is used almost universally for locomotive, portable, and semiportable engines, the comparitive immunity from accidents under the high pressures with which they are habitually worked, and the economical results obtained are well known. The boiler rests on two castings, that under the fire-box forming an ash-pan, fitted with a door in front, by which the quantity of air admitted beneath the firebars can be regulated; the other supports the smoke-box, and is used as a water tank.

DIMENSIONS AND PRICES OF LOCOMOTIVE MULTITUBULAR BOILERS, Fig. 50.

Nominal horse-power	3	4	5	6	7	8	9	10
Height of fire box	3' 4"	3' 8"	3' 10"	4' 1"	4' 1"	4' 4"	4' 4"	4' 5"
Width	2' 4½"	2' 7½"	2' 9"	2' 11½"	2' 11½"	3' 1½"	3' 1½"	3' 5½
Length	1' 10"	2' 3"	2' 3"	2' 4"	2' 4"	2' 6	2' 8"	2' 8"
Diameter of barrel	1' 10½"	2' 1½"	2' 3"	2' 5"	2' 5"	2' 7"	2' 7"	2' 10"
Length of barrel	4' 6"	5' 3"	5' 6"	5' 6"	6' 0"	6' 4"	6' 8"	6' 8"
Number of tubes	15	19	23	23	25	27	29	33
Diameter of tubes	2½"	2½"	2½"	2½"	2½"	2¼"	2½"	2½"
Price of boiler only	£48	£56	£63	£72	£77	£82	£89	£96
Price of boiler and fittings, including ash-pan and tank ..	£60	£71	£78	£87	£94	£100	£107	£118
Approx. measurement in cubic ft.	50	70	85	100	105	120	125	145
Approximate weight in cwt. ..	16¼	18	23	26	29	32	35	40

Nominal horse-power	12	14	16	18	20	25	30
Height of fire box	4' 9"	4' 10½	5' 2"	5' 9"	5' 9"	6' 0"	6' 2"
Width	3' 5½"	3' 1½"	3' 5½"	3' 11"	3' 11"	4' 2	4' 4"
Length	3' 0"	3' 3"	3' 5"	3' 9"	4' 1"	4' 0"	4' 3"
Diameter of barrel	2' 10"	3' 0¾"	3' 4¾"	3' 10¼"	3' 10¼"	4' 1½"	4' 3¼
Length of barrel	7' 3"	7' 5½"	7' 9"	8' 0¾"	8' 3½"	8' 4"	8' 8"
Number of tubes	36	37	41	47	51	60	70
Diameter of tubes	2½"	2½"	2½"	2½"	2½"	2½"	2½"
Price of boiler only	£107	£129	£152	£189	£220	£284	£331
Price of boiler and fittings, including ash-pan and tank	£129	£158	£181	£220	£252	£318	£365
Approximate measurement in cubit feet	155	165	200	270	285	310	320
Approximate weight in cwts.	45	50	58	74	80	90	100

The fittings include safety valve, stop valve, feed valve, glass water gauge, gauge cocks, blow-off cock, and patent steam-pressure gauge.

Boilers of this construction are frequently mounted on wood or wrought-iron wheels, as shown in Fig. 51. These wheels are adapted for hot or cold climates (especially the former, where they are decidedly better than ordinary wood wheels), and, although very light, are extremely strong and durable.

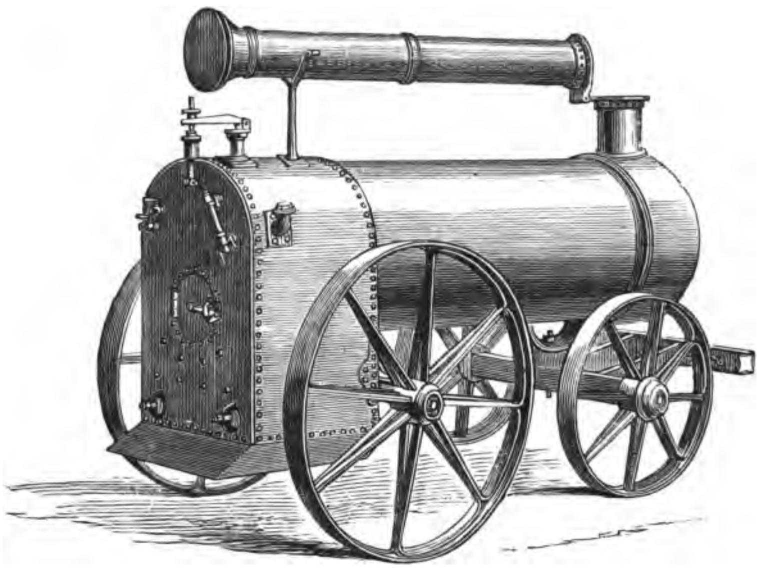


Fig. 51.

PRICES OF LOCOMOTIVE MULTITUBULAR BOILERS, mounted as in Fig. 51.

Nominal horse-power		3	4	5	6	7	8	9	10	12	14	16	18	20	25	30
Price of boiler and fittings mounted on wrought-iron wheels	£	67	72	89	100	107	116	122	134	144	176	201	247	284	160	400

The dimensions and weights are very nearly the same as those given for Fig. 50.

VERTICAL BOILERS, Fig. 52. These boilers occupy very little space, and require no brickwork setting, which causes a great saving in first outlay. The several forms of this type include the multitubular, hanging-tube, and cross-tube boiler. Recent improvements in the process of working plates admit of the shells and fire-boxes being made without any longitudinal rivetted joints, which produces an exceptionally neat appearance, is convenient for fixing the mountings, and adds greatly to their strength, owing to the perfectly cylindrical form which is thus obtained; the grooving and corrosion, which invariably first takes place at the longitudinal joints of boilers, is also avoided. These remarks refer to boilers of moderate size.

In the **VERTICAL MULTITUBULAR BOILERS** the water circulates round the tubes whilst the gases and other products of combustion pass from the fire-box through the small tubes to the smoke-box and from thence to the chimney.

The **HANGING-TUBE BOILERS** have a number of water tubes, solid at the lower end, fixed in the crown of the fire-box. The products of combustion, having been made to circulate amongst these tubes by means of a baffle plate, pass to the chimney through a straight central flue tube.

The **CROSS-TUBE BOILER** has one or more tubes, 6 in. to 8 in. in diameter, placed across the fire-box; the water circulates in these whilst the heated gases, &c., pass round their

exterior, and are then conducted by a straight flue tube to the chimney. All these boilers give good results; the two first named naturally effect greater economy in fuel, but the cross-tube boilers possess the advantage of greater simplicity of construction, and consequent facility for cleaning, rendering them peculiarly suitable for employment where only bad water can be obtained; and numbers of them have been employed with extremely satisfactory results for supplying steam to cranes, travellers, small winding and pumping engines, &c.

All of the boilers in the following list are of the best materials and workmanship, the shells being of best Staffordshire plates, and tube plates and fire-box crowns of Low Moor, Farnley, or equal quality, and are fitted with safety valve and Salter's patent spring balance, water gauge, gauge cocks, and blow-off cock, man-hole cover and bridges, mud-hole covers, fire-bars, fire-door, short chimney, &c.

Dimensions and Prices of Vertical Multitubular Boilers.

Nominal horse-power	2	4	6	8	10	12
Diameter of shell	2' 6"	2' 9"	3' 0"	3' 6"	4' 0"	4' 3"
Height of shell	5' 6"	6' 0"	7' 0"	7' 0"	8' 0"	9' 0"
Diameter of fire-box	2' 0"	2' 3"	2' 6"	3' 0"	3' 6"	3' 9"
Height of fire-box	1' 10"	2' 0"	2' 6"	2' 6"	4' 0"	4' 6"
Number of tubes	12	20	24	28	36	40
Diameter of tubes	2½"	2½"	2½"	2½"	3"	3"
Price of boiler	£28	£35	£45	£50	£80	£100
„ of boiler and fittings ..	£36	£45	£57	£65	£98	£120
„ extra for felting and lagging	£8	£10	£12	£15	£20	£25
Approximate weight in cwt. ..	14	16	20	24	40	48
„ measurement in cubic ft.	50	60	85	110	170	200

Vertical Hanging-Tube Boilers.

Nominal horse-power	2	4	6	8	10	12
Diameter of shell	2' 6"	2' 9"	3' 0"	3' 6"	4' 0"	4' 3"
Height of shell	5' 6"	6' 0"	7' 0"	7' 0"	8' 0"	9' 0"
Diameter of fire-box	2' 0"	2' 3"	2' 6"	3' 0"	3' 6"	3' 9"
Height of fire-box	2' 6"	2' 11"	3' 6"	3' 6"	4' 3"	4' 6"
Number of hanging tubes ..	12	20	24	28	36	40
Diameter of tubes	2½"	2½"	2½"	2½"	3"	3"
Price of boiler	£25	£30	£38	£45	£70	£85
„ of boiler and fittings ..	£33	£40	£50	£60	£88	£105
„ extra for felting and lagging	£8	£10	£12	£15	£20	£25
Approximate weight in cwt. ..	14	16	20	24	40	48
„ measurement in cubic ft.	50	60	85	110	170	200

Vertical Cross-Tube Boilers.

Nominal horse-power	2	4	6	8	10	12
Diameter of shell	2' 6"	2' 9"	3' 0"	3' 6"	4' 0"	4' 3"
Height of shell	5' 6"	6' 0"	7' 0"	7' 0"	8' 0"	9' 0"
Diameter of fire-box	2' 0"	2' 3"	2' 6"	3' 0"	3' 6"	3' 9"
Height of fire-box	2' 6"	2' 11"	3' 6"	3' 6"	4' 3"	4' 6"
Number of cross tubes	1	1	2	2	2	3
Diameter of tubes	6"	6"	6"	6"	8"	8"
Price of boiler	£25	£30	£38	£45	£70	£85
„ of boiler and fittings ..	£33	£40	£50	£60	£88	£105
„ extra for felting and lagging	£8	£10	£12	£15	£20	£25
Approximate weight in cwt. ..	14	16	20	24	40	48
„ measurement in cubic ft	50	60	85	110	170	200

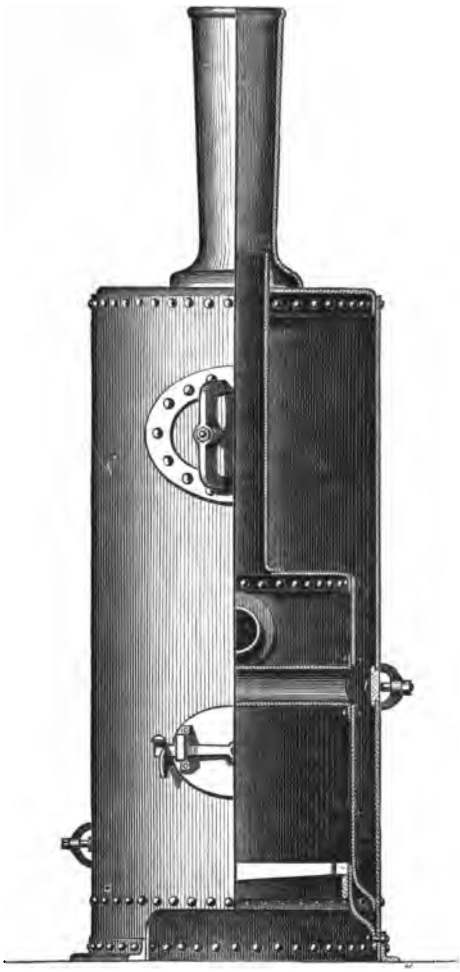


Fig. 52.

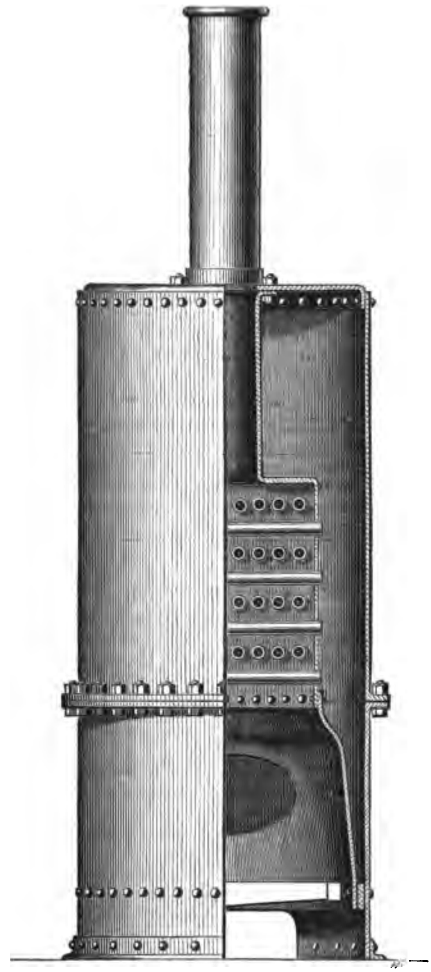


Fig. 53.

APPLEBY AND CORNES PATENT BOILER, Fig. 53, gives a maximum heating surface with a minimum weight and bulk, and experience has shown that it is at least equal to any boiler of that type in efficiency and durability, and is superior to most of them. The upper and lower portions of the shell are connected by flanged joints bolted together, and the uptake is secured to the crown plate in a similar manner. The lower part of the fire box is circular, but above the fire door it is worked into a square form to receive a square upper box, into which are fitted any number of either parallel or taper tubes, and of such diameter as may be most suitable for the size of the boiler and the heating surface required.

STAY-TUBE BOILER. Another modification of this Patent consists in making the outer shell square up to the crown of the fire box. Holes are drilled in the fire-box shell opposite to each tube; these holes being slightly larger in diameter than the tubes, the stays for the outer shell pass through the centre of each water tube, and each stay is fitted with a solid ended brass nut with a conical face, which impinges on the drilled hole in the fire-box. This forms a steam-tight joint without any cement or packing, and the nut and stay can be removed as often as may be necessary for the purpose of cleaning the tubes with a scraper, or for replacing a defective tube, without taking the boiler apart; the upper portion of the boiler is cylindrical, and the flanged bolted joint above referred to, and shown in Fig. 53, is dispensed with.

GAS BOILERS. The use of gas for generating steam is a subject which has received considerable attention, and is now successfully carried out in many places. The boilers are generally (though by no means necessarily) of the vertical type, and have either a large number of vertical smoke-tubes or water-tubes across the fire-box. APPLEBY'S Patent Boiler, described at p. 63, is very suitable for the purpose. Gas, as a fuel, has several advantages over coal, coke, &c., viz.:—No stowage room is required on the premises; it can be lighted and turned on to full pressure at a moment's notice; it can be regulated so as to keep the boiler at an almost uniform temperature, does not require the continual attention of a man, can be turned off immediately steam is no longer required, or it can be turned down and safely left, so as just to keep steam up ready for starting again. It is, however, a somewhat expensive fuel, and can certainly not be recommended for large boilers, or where coal is cheap, or a large quantity of wood or refuse can be employed. There is, however, this very important consideration, that, where a gas boiler is used, the insurance offices do not require the additional premium which is charged if an ordinary steam boiler is fixed in the premises. The saving in this item alone will go very far towards covering the extra cost in first outlay and working expenses, even where the steam has to be constantly kept up; but if the power required is small, or the work intermittent, the extra premium on a valuable stock will probably be far more than is charged for the whole of the gas consumed.

The cost of gas boilers, constructed to work with great economy, including burners and all fittings, is—

Horse-power	2	3	4
Price	£80 0 0	£100 0 0	£120 0 0

MARINE BOILERS. The limited space available in vessels almost invariably involves the use of specially-designed boilers, and hence there is great variety in form; but the plain cylindrical boiler with return smoke tubes, as shown in the steam-tug, Fig. 28, is the type generally employed, and is, therefore, referred to in the accompanying Price List. This form of boiler occupies but small space, has a large heating surface, and being cylindrical, great strength is obtained without the introduction of the complicated stays required in most of the boilers which are specially designed with a view of economising room.

PRICES OF CYLINDRICAL MARINE BOILERS.

Nominal horse-power	6	8	10	12	15	20
Diameter of boiler..	4' 3"	4' 6"	5' 0"	5' 3"	5' 6"	5' 9"
Length of boiler	5' 6"	6' 0"	6' 6"	7' 0"	7' 0"	8' 0"
Diameter of grate flue	2' 3"	2' 4"	2' 6"	2' 9"	2' 9"	3' 0"
„ of return tubes	2¼"	2⅜"	2⅜"	2½"	2⅜"	2⅝"
Number of return tubes	30	36	42	48	50	50
Diameter of dome	1' 6"	2' 0"	2' 0"	2' 0"	2' 0"	2' 3"
Height of dome	1' 6"	2' 0"	2' 0"	2' 0"	2' 0"	2' 3"
Price of boiler with smoke-box and chimney	£100	£120	£135	£150	£175	£225
Price of boiler and fittings ..	£115	£138	£155	£175	£200	£250
Approximate weight in cwt. ..	32	48	56	66	75	85
„ measurement in cubic ft.	100	120	165	190	210	270

The fittings included in the second price, in addition to furnace work, are safety valve with Salter's spring balance, glass water-gauge, gauge cocks, blow-off cock, scum cock, steam-pressure gauge, and fusible plug. The measurements are given exclusive of dome.

FUEL-FEEDING APPARATUS, or **STEAM STOKER,** Fig. 54. The advantages of an uniform admission of fuel to the furnaces of boilers (instead of the more usual plan of feeding at irregular intervals) are so obvious that it is not surprising so many attempts have been made to introduce mechanical stokers. Amongst the earliest was that known as Jucke's, in in which the fuel is placed on an endless chain carried by two rollers driven by the engine.

This endless chain forms the fire-bars, and moves so slowly that the unburnt fuel placed on it at the furnace mouth is delivered at the back of the furnace in the form of ashes and clinkers. The rollers and chain are carried on a sort of trolly, so that the whole can be drawn out when necessary, and the furnace is made adjustable to regulate the supply of fuel. Many of these are still in use, but Jucke's furnace now has many competitors, and Henderson's Mechanical Stoker, Fig. 54, is one of the most successful. In this apparatus a hopper is placed over the fire door, into which the fuel is put, and from which it is gradually fed into the furnace by automatic gear driven from the engine. The prices of these stokers range from £55 to £70. according to size.

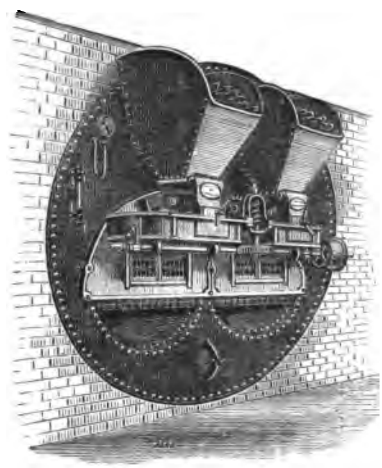


Fig. 54.

HENDERSON'S PATENT MOVABLE FIRE-BARS are also useful in reducing the amount of ash made, and are worth 15*s.* 6*d.* per cwt., including all the furnace work connected therewith.

SELF-ACTING DAMPERS. The regulation of the quantity of air admitted to a boiler furnace is a very important point, and as firemen do not always attend to the ordinary dampers, several self-adjusting dampers have been employed with excellent results. That illustrated in Fig. 55 is a good example. In this damper the opening is regulated by the steam pressure in the boiler, and it can be adjusted to suit the required pressure

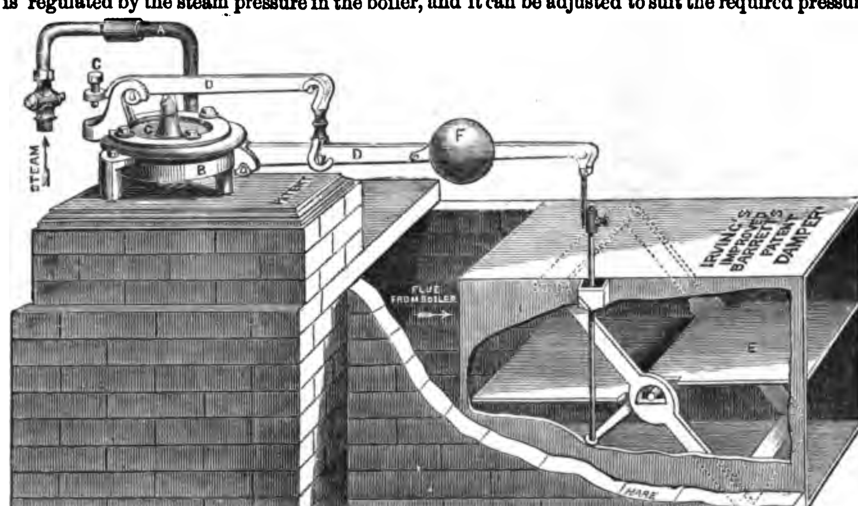


Fig. 55.

by shifting the balance ball. There is a small stop which prevents the damper from closing entirely, so that the smoke always has free exit. The price of these dampers is £19 each, and they are made to suit the dimensions of the flue to which they are intended to be applied.

SMOKE-CONSUMING APPARATUS. The number of methods proposed for consuming smoke is so great that it would be impossible even to enumerate them here; it may not, however, be out of place to mention a few of the principal ones. Papin proposed to make the smoke descend through the fire, the necessary draught being obtained by a blower, and although this idea is excellent in theory, it has been found impracticable. The plan adopted by Watt was to

place a wide dead-plate between the furnace doors and the fire bars, and on it coke the coal before burning it. In this method the smoke and gases evolved from the fresh coal is consumed whilst passing over the incandescent mass of fuel at the back of the furnace, and it is so simple and effective that, by carefully placing the fresh coal in the front part of the fire grate and leaving it there to coke, any ordinary furnace may be made to work very nearly smokelessly. Many schemes for smoke-consuming have been designed on the principle of introducing a quantity of air *above* the fire-bars sufficient to ensure the combustion of the smoke, &c., but it has generally been found too difficult to regulate the supply of air, as when the furnace receives a fresh charge of coal, a larger quantity of air is required than at other times; if, however, a mechanical stoker (such as Henderson's, Fig. 54) is used, the admission of air through the ventilators in the fire door can be accurately regulated; and it should not be forgotten that in consuming smoke we not only get rid of a nuisance, but obtain a marked saving of fuel. Prideaux's fire doors, in which the air enters through a number of Venetian lattices, and is warmed by contact with metal plates before reaching the furnace, have given good results.

FEED-WATER HEATER. Amongst the various contrivances for economising fuel, none have better attained their object than feed-water heaters. The kind shown in the engraving of the horizontal condensing engine, Fig. 3, have been applied to many engines with very satisfactory results. The heater consists of a cylindrical casing having a separate chamber at each end; the two chambers are connected by a number of small tubes through which the water is forced, and whilst traversing them, it takes up a certain portion of heat from the exhaust steam which circulates outside the tubes.

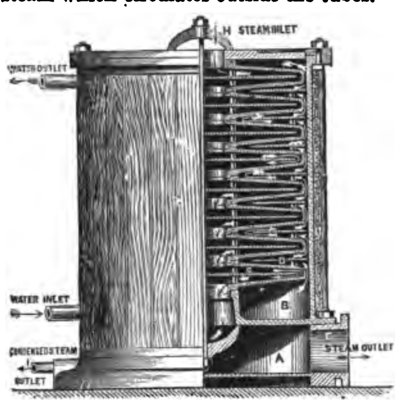


Fig. 56.

Another good form of feed-water heater is that shown in Fig. 56, consisting of a cast-iron cylindrical casing divided up by a number of discs and diaphragms. The exhaust steam is caused to circulate *inside* these diaphragms, whilst the feed water traverses the *outside*, the latter naturally absorbing a great deal of heat from the former. A small pipe is shown at the bottom for carrying off such of the steam as may be condensed. The outside of the casting is felted and lagged with mahogany, which gives it a neat appearance, and adds to its efficiency. It is sometimes urged against water heaters that they soon get choked with deposit when the water used is at all foul, but it should not be forgotten that all the sediment would have settled in the boiler if it had not been arrested in the heater, and that it is a comparatively easy matter to clean the heaters.

PRICES, &c., OF APPLEBY'S FEED-WATER HEATER.

Nominal horse-power engine	4 to 8	9 to 12	12 to 15	15 to 18	18 to 22	22 to 25	25 to 30	30 to 35	35 to 40	40 to 50
Price of suitable water heater	£12	13 10	15	17	19	22	25	29	34	40

PRICES, &c., OF WATER HEATER, Fig. 56.

Nominal horse-power of engine	4 to 8	9 to 12	12 to 15	15 to 18	18 to 22	22 to 25	25 to 30	30 to 35	35 to 40	40 to 50
Price of suitable water heater	£16	£18	£20	£22	£25	£29	£33	£38	£45	£55
Height of suitable water heater	24″	29″	28″	34″	30″	36″	36″	42″	42″	51″
Diameter	15″	15″	18″	18″	21″	21″	24″	24″	30″	30″
Diameter of steam inlet	2½″	3″	3½″	4″	4″	4½″	5½″	6″	6½″	7″
Approximate weight in cwt.	6½	7½	9½	11	12	14	18½	22	30	37
" measurement in cubic ft. ..	13	16	21	24	32	36	40	43	51	56

Extra for felting and lagging about 2½ per cent.

USEFUL TABLES AND MEMORANDA RELATING TO PRIME MOVERS.

AREAS AND CIRCUMFERENCES OF CIRCLES ADVANCING BY EIGHTHS OF AN INCH.

AREAS.									CIRCUMFERENCES.									
Diam.	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8	Diam.	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8	Diam.
0	.0000	.0122	·0490	.1104	.1963	.3068	.4417	.6013	0	.0	.3927	.7854	1.178	1.570	1.963	2.356	2.748	0
1	.7854	.9940	1.227	1.484	1.767	2·073	2.405	2.761	1	3.141	3.534	3.927	4.319	4.712	5.105	5.497	5.890	1
2	3.141	3.546	3.976	4.430	4.908	5.411	5.939	6.491	2	6.283	6.675	7.068	7.461	7.854	8.246	8.639	9.032	2
3	7.068	7 669	8.295	8.946	9.621	10.32	11.04	11.79	3	9.424	9.817	10.21	10.60	10.99	11.38	11.78	12.17	3
4	12.76	13.36	14.18	15.03	15.90	16.80	17.72	18.76	4	12.56	12.95	13.35	13.74	14.13	14.52	14.92	15.31	4
5	19.63	20.62	21.64	22.69	23.75	24.85	25.96	27.10	5	15.70	16.10	16.49	16.88	17.27	17.67	18.06	18.45	5
6	28.27	29.46	30.67	31.91	33.18	34.47	35.78	37.12	6	18.88	19.24	19.63	20.02	20.42	20.81	21.20	21.59	6
7	38.48	39.87	41.28	42.71	44.17	45.66	47.17	48.70	7	21.99	22.38	22.77	23.16	23.56	23.95	24.34	24.78	7
8	50.26	51.84	53.45	55.08	56.74	58.42	60.13	61.86	8	25.13	25.52	25.91	26.31	26.70	27.09	27.48	27.88	8
9	63.61	65.39	67.20	69.02	70.88	72.75	74.76	76.58	9	28.27	28.66	29.05	29.45	29.84	30.23	30.63	31.02	9
10	78.54	80.51	82.51	84.54	86.59	88.66	90.76	92.88	10	31.41	31.80	32.20	32.59	32.98	33.37	33.77	34.16	10
11	95.03	97.20	99.40	101.6	103.8	106.1	108.4	110.7	11	34.55	34.95	35.34	35.73	36.12	36.52	36.91	37.30	11
12	113.0	115.4	117.8	120.2	122.7	125.1	127.6	130.1	12	37.69	38.09	38.48	38.87	39.27	39.66	40.05	40.44	12
13	132.7	135.2	137.8	140.5	143.1	145.8	148.4	151.2	13	40.84	41.23	41.62	42.01	42.41	42.80	43.19	43.58	13
14	153.9	156.6	159.4	162.2	165.1	167.9	170.8	173.7	14	43.98	44.35	44.76	45.16	45.55	45.94	46.33	46.73	14
15	176.7	179.6	182.6	185.6	188.6	191.7	194.8	197.9	15	47.12	47.51	47.90	48.30	48.59	49.08	49.48	49.87	15
16	201.0	204.2	207.3	210.5	213.8	217.0	220.3	223.6	16	50.26	50.65	51.05	51.44	51.83	52.22	52.62	53.01	16
17	226.9	230.3	233.7	237.1	340.5	343.9	247.4	250.9	17	53.40	53.79	54.19	54.58	54.97	55.37	55.76	56.15	17
18	254.4	258.0	261.5	265.1	268.8	272.4	276.1	279.8	18	56.54	56.94	57.33	57.72	58.11	58.51	58.90	59.29	18
19	283.5	287.2	291.0	294.8	298.6	302.4	306.3	310.2	19	59.69	60.08	60.47	60.86	61.26	61.65	62.04	62.43	19
20	314.1	318.1	322.0	326.0	330.0	334.1	338.1	342.2	20	62.83	63.22	63.61	64.01	64.40	64.79	65.18	65.58	20
21	346.3	350.4	354.6	358.8	363.0	367.2	371.5	375.8	21	65.97	66.36	66.75	67.15	67.54	67.93	68.32	68.72	21
22	380.1	384.4	388.8	393.2	397.6	402.0	406.4	410.9	22	69.11	69.50	69.90	70.29	70.68	71.07	71.47	71.86	22
23	415.4	420.0	424.5	429.1	433.7	438.3	443.0	447.6	23	72.25	72.64	73.04	73.43	73.82	74.22	74.61	75.00	23
24	452.3	457.1	461.8	466.6	471.4	476.2	481.1	485.9	24	75.39	75.79	76.18	76.57	76.96	77.36	77.75	78.14	24
25	490.8	495.7	500.7	505.7	510.7	515.7	520.7	525.8	25	78.54	78.93	79.32	79.71	80.10	80.50	80.89	81.28	25
26	530.9	536.0	541.1	546.3	551.5	556.7	562.0	567.2	26	81.68	82.07	82.46	82.85	83.25	83.64	84.03	84.43	26
27	572.5	577.8	583.2	588.5	593.9	599.3	604.8	610.2	27	84.82	85.21	85.60	86.00	86.39	86.78	86.17	87.57	27
28	615.7	621.2	625.7	632.3	637.9	643.5	649.1	654.8	28	87.96	88.35	88.75	89.14	89.53	89.92	90.32	90.71	28
29	660.5	666.2	671.9	677.7	683.4	689.2	695.1	700.9	29	91.10	91.49	91.89	92.28	92.67	93.06	93.46	93.85	29
30	706.8	712.7	718.6	724.6	730.6	736.6	742.6	748.6	30	94.24	94.64	95.03	95.42	95.81	96.21	96.60	96.99	30
31	754.8	760.9	767.0	773.1	779.3	785.5	791.7	798.0	31	97.39	97.78	98.17	98.56	98.96	99.35	99.74	100.1	31
32	804.2	810.5	816.9	823.2	829.6	836.0	842.4	848.8	32	100.5	100.9	101.3	101.7	102.1	102.5	102.9	103.3	32
33	855.3	861.8	868.3	874.8	881.4	888.0	894.6	901.3	33	103.7	104.1	104.5	104.9	105.2	105.6	106.0	106.4	33
34	907.9	914.6	921.3	928.1	934.8	941.6	948.4	955.3	34	106.8	107.2	107.6	108.0	108.4	108.8	109.2	109.6	34
35	962.1	969.0	975.9	982.8	989.8	996.8	1003	1010	35	110.0	110.3	110.7	111.1	111.5	111.9	112.3	112.7	35
36	1017	1025	1032	1039	1046	1053	1060	1068	36	113.1	113.5	113.9	114.3	114.7	115.1	115.5	115.8	36
37	1075	1082	1089	1097	1104	1111	1119	1126	37	116.2	116.6	117.0	117.4	117.8	118.2	118.6	119.0	37
38	1134	1141	1149	1156	1164	1171	1179	1186	38	119.4	119.8	120.2	120.6	121.0	121.3	121.7	122.1	38
39	1194	1202	1210	1217	1225	1233	1241	1248	39	122 5	122.9	123.3	123.7	124.1	124.5	124.9	125.3	39
40	1256	1264	1272	1280	1288	1296	1304	1312	40	125.7	126.1	126.4	126.8	127.2	127.6	128.0	128.4	40
41	1320	1328	1336	1344	1352	1360	1369	1377	41	128.8	129.2	129.6	130.0	130.4	130.8	131.2	131.6	41
42	1385	1393	1402	1410	1418	1427	1435	1443	42	131.9	132.3	132.7	133.1	133.5	133.9	134.3	134.7	42
43	1452	1460	1469	1477	1486	1494	1503	1511	43	135.1	135.5	135.9	136.3	136.7	137.1	137.4	137.8	43
44	1520	1529	1537	1546	1555	1564	1572	1581	44	138.2	138.6	139.0	139.4	139.8	140.2	140.6	141.0	44
45	1590	1599	1608	1617	1626	1634	1643	1652	45	141.4	141.8	142.2	142.6	142.9	143.3	143.7	144.1	45
46	1661	1671	1680	1689	1698	1707	1716	1725	46	144.5	144.9	145.3	145.7	146.1	146.5	146.9	147.3	46
47	1734	1744	1753	1762	1772	1781	1790	1800	47	147.7	148.0	148.4	148.8	149.2	149.6	150.0	150.4	47
48	1809	1819	1828	1837	1847	1854	1868	1876	48	150.8	151.2	151.6	152.0	152.4	152.8	153.2	153.5	48
49	1885	1895	1905	1914	1924	1934	1943	1953	49	153.9	154.3	154.7	155.1	155.5	155.9	156.3	156.7	49
50	1963	1973	1983	1993	2003	2012	2022	2032	50	157.1	157.5	157.9	158.3	158.7	159.0	159.4	159.8	50

D = Diameter. $D = \frac{C}{3.14159}$ or $\sqrt{A \div .7854}$ or $C \times .31831$.

A = Area. $A = D^2 \times .7854$ or $(C \div 3.5446)^2$.

C = Circumference. $C = D \times 3.14159$ or $3.5446 \sqrt{A}$.

S = Contents of Sphere. $S = D^3 \times .5236$.

B = Contents of Cylinder. $B = A \times$ length. (A being the area of one end.)

For Areas, &c., of higher numbers, see next page.

TABLE OF DIAMETERS, AREAS, AND CIRCUMFERENCES OF CIRCLES,

AND OF

SQUARES, CUBES, SQUARE ROOTS AND CUBE ROOTS.

Number.	Circumference.	Area.	Square.	Cube.	Square Root.	Cube Root.	Number.	Circumference	Area.	Square.	Cube.	Square Root.	Cube Root.
1	3·14	0·79	1	1	1·000	1·000	61	191·64	2922·47	3721	226981	7·810	3·936
2	6·28	3·14	4	8	1·414	1·260	62	194·78	3019·07	3844	238328	7·874	3·957
3	9·42	7·07	9	27	1·732	1·442	63	197·92	3117·25	3969	250047	7·937	3·979
4	12·57	12·57	16	64	2·000	1·587	64	201·06	3216·99	4096	262144	8·000	4·000
5	15·71	19·63	25	125	2·236	1·710	65	204·20	3318·31	4225	274625	8·062	4·020
6	18·85	28·27	36	216	2·450	1·817	66	207·35	3421·19	4356	287496	8·124	4·041
7	21·99	38·48	49	343	2·646	1·913	67	210·49	3525·65	4489	300763	8·185	4·061
8	25·13	50·27	64	512	2·828	2·000	68	213·63	3631·68	4624	314432	8·246	4·081
9	28·27	63·62	81	729	3·000	2·080	69	216·77	3739·28	4761	328509	8·306	4·101
10	31·42	78·54	100	1000	3·162	2·154	70	219·91	3848·45	4900	343000	8·367	4·121
11	34·56	95·03	121	1331	3·317	2·224	71	223·05	3959·19	5041	357911	8·426	4·140
12	37·70	113·10	144	1728	3·464	2·289	72	226·19	4071·50	5184	373248	8·485	4·160
13	40·84	132·73	169	2197	3·605	2·351	73	229·34	4185·39	5329	389017	8·544	4·179
14	43·98	153·94	196	2744	3·741	2·410	74	232·48	4300·84	5476	405224	8·602	4·198
15	47·12	176·72	225	3375	3·872	2·466	75	235·62	4417·86	5625	421875	8·660	4·217
16	50·27	201·06	256	4096	4·000	2·519	76	238·76	4536·46	5776	438976	8·717	4·235
17	53·41	226·98	289	4913	4·123	2·571	77	241·90	4656·63	5929	456533	8·775	4·254
18	56·55	254·47	324	5832	4·242	2·620	78	245·04	4778·36	6084	474552	8·831	4·272
19	59·69	283·53	361	6859	4·358	2·668	79	248·19	4901·67	6241	493039	8·888	4·290
20	62·83	314·15	400	8000	4·472	2·714	80	251·33	5026·55	6400	512000	8·944	4·309
21	65·97	346·36	441	9261	4·582	2·758	81	254·47	5153·00	6561	531441	9·000	4·326
22	69·12	380·13	484	10648	4·690	2·802	82	257·61	5281·02	6724	551368	9·055	4·344
23	72·26	415·48	529	12167	4·795	2·843	83	260·75	5410·61	6889	571787	9·110	4·362
24	75·40	452·39	576	13824	4·898	2·884	84	263·89	5541·77	7056	592704	9·165	4·379
25	78·54	490·87	625	15625	5·000	2·924	85	267·04	5674·50	7225	614125	9·219	4·396
26	81·68	530·93	676	17576	5·099	2·962	86	270·18	5808·80	7396	636056	9·273	4·414
27	84·82	572·56	729	19683	5·196	3·000	87	273·32	5944·69	7569	658503	9·327	4·431
28	87·96	615·75	784	21952	5·291	3·036	88	276·46	6082·12	7744	681472	9·380	4·447
29	91·11	660·52	841	24389	5·385	3·072	89	279·60	6221·14	7921	704969	9·433	4·461
30	94·25	706·86	900	27000	5·477	3·107	90	282·74	6361·72	8100	729000	9·487	4·481
31	97·39	754·77	961	29791	5·567	3·141	91	285·89	6503·88	8281	753571	9·539	4·497
32	100·53	804·25	1024	32768	5·657	3·174	92	289·03	6647·61	8464	778688	9·591	4·514
33	103·67	855·30	1089	35937	5·744	3·207	93	292·17	6792·91	8649	804357	9·643	4·530
34	106·82	907·92	1156	39304	5·830	3·239	94	295·31	6939·78	8836	830584	9·695	4·546
35	109·96	962·11	1225	42875	5·916	3·271	95	298·45	7088·22	9025	857375	9·746	4·562
36	113·10	1017·88	1296	46656	6·000	3·301	96	301·59	7238·23	9216	884736	9·797	4·578
37	116·24	1075·21	1369	50653	6·082	3·332	97	304·73	7389·81	9409	912673	9·848	4·594
38	119·38	1134·11	1444	54872	6·164	3·361	98	307·87	7542·96	9604	941192	9·899	4·610
39	122·52	1194·59	1521	59319	6·244	3·391	99	311·02	7697·69	9801	970299	9·949	4·626
40	125·66	1256·64	1600	64000	6·324	3·419	100	314·16	7853·98	10000	1000000	10·000	4·642
41	128·81	1320·25	1681	68921	6·403	3·448	101	317·30	8011·85	10201	1030301	10·049	4·657
42	131·95	1385·44	1764	74088	6·480	3·476	102	320·44	8171·28	10404	1061208	10.099	4·672
43	135·09	1452·20	1849	79507	6·557	3·503	103	323·58	8332·29	10609	1092727	10·148	4·687
44	138·23	1520·53	1936	85184	6·633	3.530	104	326·73	8494·87	10816	1124864	10·198	4·702
45	141·37	1590·43	2025	91125	6·708	3·556	105	329·87	8659·01	11025	1157625	10·246	4·717
46	144·51	1661·90	2116	97336	6·782	3·583	106	333·01	8824·73	11236	1191016	10·295	4·732
47	147·66	1734·94	2209	103823	6·856	3·609	107	336·15	8992·02	11449	1225043	10·344	4·747
48	150·80	1809·56	2304	110592	6·928	3·634	108	339·29	9160·88	11664	1259712	10·392	4·762
49	153·94	1885·74	2401	117649	7·000	3.659	109	342·43	9331·32	11881	1295029	10·440	4·776
50	157·08	1963·50	2500	125000	7·071	3·684	110	345·58	9503·32	12100	1331000	10·488	4·791
51	160·22	2042·82	2601	132651	7·141	3·708	111	348·72	9676·89	12321	1367631	10·536	4·806
52	163·36	2123·72	2704	140608	7·211	3·732	112	351·86	9852·03	12544	1404928	10·583	4·820
53	166·50	2206·18	2809	148877	7·280	3·756	113	355·00	10028·75	12769	1442897	10·630	4·834
54	169·65	2290·22	2916	157464	7·348	3·779	114	358·14	10207·03	12996	1481544	10·677	4·848
55	172·79	2375·83	3025	166375	7·416	3·802	115	361·28	10386·89	13225	1520875	10·723	4·862
56	175·93	2463·01	3136	175616	7·483	3·825	116	364·42	10568·32	13456	1560896	10·770	4·876
57	179·07	2551·76	3249	185193	7·549	3·848	117	367·56	10751·32	13689	1601613	10·816	4·890
58	182·21	2642·08	3364	195112	7·615	3·870	118	370·70	10935·88	13924	1643032	10·862	4·904
59	185·35	2733·97	3481	205379	7·681	3·892	119	373·85	11122·02	14161	1685159	10·908	4·918
60	188·50	2827·43	3600	216000	7·746	3·915	120	376·99	11309·73	14400	1728000	10·954	4·932

TABLE OF DIAMETERS, AREAS, &c.—*continued.*

Number.	Circumference.	Area.	Square.	Cube.	Square Root.	Cube Root.	Number.	Circumference.	Area.	Square.	Cube.	Square Root	Cube Root.
121	380.18	11499·01	14641	1771561	11·000	4·946	186	584·34	27171·6	34596	6434856	13·638	5·708
122	383·27	11689·87	14884	1815848	11·045	4·959	187	587·48	27464·6	34969	6539203	13·674	5·718
123	386·41	11882·29	15129	1860867	11·090	4·973	188	590·62	27759·1	35344	6644672	13·711	5·728
124	389·56	12076·28	15376	1906624	11·135	4·986	189	593·76	28055·2	35721	6751269	13·747	5·738
125	392·70	12271·85	15625	1953125	11·180	5·000	190	596·90	28352·9	36100	6859000	13·784	5·748
126	395·84	12468·98	15876	2000376	11·224	5·013							
127	398·98	12667·69	16129	2048383	11·269	5·026	191	600·04	28652·1	36481	6967871	13·820	5·758
128	402·12	12867·96	16384	2097152	11·314	5·039	192	603·19	28952·9	36864	7077888	13·856	5·768
129	405·27	13069·81	16641	2146689	11·357	5·052	193	606·33	29255·3	37249	7189057	13·892	5·778
130	408·41	13273·23	16900	2197000	11·401	5·065	194	609·47	29559·2	37636	7301384	13·928	5·788
							195	612·61	29864·8	38025	7414875	13·964	5·798
131	411·55	13478·22	17161	2248091	11·445	5·078	196	615·75	30171·9	38416	7529536	14·000	5·808
132	414·69	13684·78	17424	2299968	11·489	5·091	197	618·89	30480·5	38809	7645373	14·035	5·818
133	417·83	13892·91	17689	2352637	11·532	5·104	198	622·04	30790·7	39204	7762392	14·071	5·828
134	420·97	14102·61	17956	2406104	11·575	5·117	199	625·18	31102·6	39601	7880599	14·106	5·838
135	424·12	14313·88	18225	2460375	11·618	5·129	200	628·32	31415·9	40000	8000000	14·142	5·848
136	427·26	14526·72	18496	2515456	11·661	5·142							
137	430·40	14741·14	18769	2571353	11·704	5·155	201	631·46	31730·9	40401	8120601	14·177	5·857
138	433·54	14957·12	19044	2620872	11·747	5·167	202	634·60	32047·4	40804	8242408	14·212	5·867
139	436·68	15174·68	19321	2685619	11·789	5·180	203	637·74	32365·5	41209	8365427	14·247	5·877
140	439·82	15393·80	19600	2744000	11·832	5·192	204	640·88	32685·1	41616	8489664	14·282	5·886
							205	644·03	33006·4	42025	8615125	14·317	5·896
141	442·96	15614·50	19881	2803221	11·874	5·204	206	647·17	33329·2	42436	8741816	14·352	5·905
142	446·11	15836·77	20164	2863288	11·916	5·217	207	650·31	33653·5	42849	8869743	14·387	5·915
143	449·25	16060·61	20449	2924207	11·958	5·229	208	653·45	33979·5	43264	8998912	14·422	5·924
144	452·39	16286·02	20736	2985984	12·000	5·241	209	656·59	34307·0	43681	9123329	14·456	5·934
145	455·53	16513·00	21025	3048625	12·041	5·253	210	659·63	34636·1	44100	9261000	14·491	5·943
146	458·67	16741·55	21316	3112136	12·083	5·265							
147	461·81	16971·67	21609	3176523	12·124	5·277	211	662·87	34966·7	44521	9393931	14·525	5·953
148	464·96	17203·36	21904	3241792	12·165	5·289	212	666·01	35298·9	44944	9528128	14·560	5·962
149	468·10	17436·62	22201	3307949	12·206	5·301	213	669·16	35632·7	45369	9663597	14·594	5·972
150	471·24	17671·46	22500	3375000	12·247	5·313	214	672·30	35968·1	45796	9800344	14·628	5·981
							215	675·44	36305·0	46225	9938375	14·662	5·990
151	474·38	17907·86	22801	3442951	12·288	5·325	216	678·58	36643·5	46656	10077696	14·696	6·000
152	477·52	18145·84	23104	3511808	12·328	5·336	217	681·73	36983·6	47089	10218313	14·730	6·009
153	480·66	18385·39	23409	3581577	12·369	5·348	218	684·87	37325·3	47524	10360232	14·764	6·018
154	483·81	18626·50	23716	3652264	12·409	5·360	219	688·01	37668·5	47961	10503459	14·798	6·027
155	486·95	18869·19	24025	3723875	12·449	5·371	220	691·15	38013·3	48400	10648000	14·832	6·036
156	490·09	19113·45	24336	3796416	12·489	5·383							
157	493·23	19359·28	24649	3869893	12·529	5·394	221	694·29	38359·6	48841	10793861	14·866	6·045
158	496·37	19606·68	24964	3944312	12·569	5·406	222	097·43	38707·6	49284	10941048	14·899	6·055
159	499·51	19855·65	25281	4019679	12·609	5·417	223	700·57	39057·1	49729	11089567	14·933	6·064
160	502·65	20106·19	25600	4096000	12·649	5·428	224	703·71	39408·1	50176	11239424	14·966	6·073
							225	706·86	39760·8	50625	11390625	15·000	6·082
161	505·80	20358·31	25921	4173281	12·688	5·440	226	710·00	40115·0	50076	11543176	15·033	6·091
162	508·94	20611·99	26244	4251528	12·727	5·451	227	713·14	40470·8	51529	11697083	15·066	6·100
163	512·08	20867·19	26569	4330747	12·767	5·462	228	716·28	40828·1	51984	11852352	15·099	6·109
164	515·22	21124·07	26896	4410944	12·806	5·473	229	719·42	41187·1	52441	12008989	15·132	6·118
165	518·36	21382·47	27225	4492125	12·845	5·484	230	722·57	41547·6	52900	12167000	15·165	6·126
166	521·50	21642·43	27556	4574296	12·884	5·495							
167	524·65	21904·0	27889	4657463	12·922	5·506	231	725·71	41909·6	53361	12326391	15·198	6·135
168	527·79	22167·1	28224	4741632	12·961	5·517	232	728·85	42273·3	53824	12487168	15·231	6·144
169	530·93	22431·8	28561	4826809	13·000	5·528	233	731·99	42638·5	54289	12649337	15·264	6·153
170	534·07	22698·0	28900	4913000	13·038	5·539	234	735·13	43005·3	54756	12812904	15·297	6·162
							235	738·27	43373·6	55225	12977875	15·329	6·171
171	537·21	22965·8	29241	5000211	13·076	5·550	236	741·42	43743·5	55696	13144256	15·362	6·179
172	540·36	23235·2	29584	5088448	13·114	5·561	237	744·56	44115·0	56169	13312053	15·394	6·188
173	543·50	23506·2	29929	5177717	13·152	5·572	238	747·70	44488·1	56644	13481272	15·427	6·197
174	546·64	23778·7	30276	5268024	13·190	5·582	239	750·84	44862·7	57121	13651919	15·459	6·205
175	549·78	24052·8	30625	5359375	13·228	5·593	240	753·98	45238·9	57600	13824000	15·491	6·214
176	552·92	24328·5	30976	5451776	13·266	5·604							
177	556·06	24605·7	31329	5545233	13·304	5·614	241	757·12	45616·7	58081	13997521	15·524	6·223
178	559·20	24884·6	31684	5639752	13·341	5·625	242	760·27	45996·1	58564	14172488	15·556	6·231
179	562·34	25164·9	32041	5735339	13·379	5·635	243	763·41	46377·0	59049	14348907	15·588	6·240
180	565·49	25446·9	32400	5832000	13·416	5·646	244	766·55	46759·5	59536	14526784	15·620	6·248
							245	769·69	47143·5	60025	14706125	15·652	6·257
181	568·63	25730·4	32761	5929741	13·453	5·656	246	772·83	47529·2	60516	14886936	15·684	6·265
182	571·77	26015·5	33124	6028568	13·490	5·667	247	775·97	47916·4	61009	15069223	15·716	6·274
183	574·91	26302 2	33489	6128487	13·527	5·677	248	779·11	48305·1	61504	15252992	15·748	6·282
184	578·05	26590·4	33856	6229504	13·564	5·687	249	782·26	48695·5	62001	15438249	15·779	6·291
185	581·19	26880·3	34225	6331625	13·601	5·698	250	785·40	49087·4	62500	15625000	15·811	6·299

APPROXIMATE RULES.

BOILERS. An ordinary furnace requires 24 lbs. or 300 cubic feet of air for the consumption of each lb. of coal, but by means of the fan or steam jet the quantity may be reduced to 18 lbs. or 220 cubic feet. From 13 to 20 lbs. of fuel may be consumed per square foot of fire-grate, and in Cornish, Lancashire, or egg-end boilers, about three-fourths of a square foot are required to evaporate a cubic foot of water.

For each nominal horse power a boil‹r of any of the types enumerated above requires approximately—

1 cubic foot of water per hour.
1 cubic yard capacity.
1 square foot of fire-grate surface.
1 square yard of heating surface.

FORMULA FOR FINDING THE HEATING AND GRATE SURFACES.

F = Fire-grate surface in square feet.
N = Nominal horse-power.
H = Heating surface in square feet.

$$N = \sqrt{F\,H} \qquad H = \frac{N^2}{F} \qquad F = \frac{N^2}{H}.$$

FIRE-BARS should incline from the fire-door downwards at least 1 in 12, and cylindrical boilers should be set with an inclination of one-half inch in 10 feet towards the blow-off cock.

THE DEAD PLATE of a furnace should be 2 feet 8 inches above the floor line of stoke hole.

WATER LEVEL IN BOILERS.—The least depth of water above the furnace flue should be 4 inches, and the working depth about 9 inches.

PRIMING.—A large dome or steam chest tends to prevent priming, but a perforated tube in which the steam is collected inside the boiler is a still greater aid in this direction.

The following FORMULA for FINDING the AREA of CHIMNEYS for STATIONARY BOILERS may be useful:—

Q = lbs. of coal consumed per hour.
H = Height of chimney in feet.
P = Indicated (not nominal) horse-power of engine.
A = The area of the top of the chimney in square inches.

$$A = \frac{15\,Q}{\sqrt{H}} \quad \text{or} \quad \frac{15\,0\,P}{\sqrt{H}}.$$

The diameter of the base of a chimney should not be less than one-tenth of the height.

MULTITUBULAR BOILERS (not Marine). Each nominal horse-power requires approximately—

1 cubic foot of water per hour.
$\frac{1}{2}$ square foot of firegrate surface.
10 square inches sectional area of tubes.
13 square inches of flue area.
6 square inches of chimney area.
2 cubic feet of steam space.
8 cubic feet total capacity.
10 square feet of heating surface, if the whole tube surface be taken as effective.

TABLE OF THE STRONGEST PROPORTIONS OF RIVETTED JOINTS FOR BOILERS.

Thickness of Plates. Inches.	Diameter of Rivet. Inches.	Length of Rivet. Inches.	Pitch of Rivet. Inches.	Lap of Plates. Inches.
$\frac{3}{16}$	$\frac{3}{8}$	0.85	1.14	1.14
$\frac{1}{4}$	$\frac{1}{2}$	1.12	1.5	1.5
$\frac{5}{16}$	$\frac{5}{8}$	1.39	1.55	1.76
$\frac{3}{8}$	$\frac{3}{4}$	1.68	1.87	2.1
$\frac{1}{2}$	$\frac{3}{4}$	2.25	2.0	2.25
$\frac{5}{8}$	1	2.82	2.5	2.82
$\frac{3}{4}$	$\frac{1}{8}$	3.37	3.0	3.37

TABLE FOR FINDING THE SURFACE OF BOILER OR CONDENSER TUBES.

Diameter of tube in inches ..	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
Surface in square feet per foot run	.0982	.1309	.1638	.1963	.2291	.2618	.2945	.3270
Diameter of tube in inches ..	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{1}{4}$
Surface in square feet per foot run	.3599	.3927	.4253	.4580	.4908	.5235	.5563	.5890
Diameter of tube in inches ..	$2\frac{3}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$
Surface in square feet per foot run	.6218	.6544	.6873	.7199	.7526	.7853	.8508	.9158

TABLE OF PROPERTIES OF SATURATED STEAM.

Pressure in lbs. per square inch, including Atmosphere.	Pressure in lbs. per square inch, excluding Atmosphere.	Equivalent inches of Mercury.	Pressure in Kilogrammes per square centimetres.	Equivalent metres of Mercury.	Number of Atmospheres.	Temperature in degrees Fahrenheit. (Sensible Heat.)	Temperature in degrees Centigrade. (Sensible Heat.)	Total Heat in degrees Fahrenheit, latent included.	Specific Volume (compared with Water).	Weight of 1 cubic foot of Steam in lbs.	Volume of 1 lb. of Steam in cubic feet.
14·7	0.0	29.922	1.033	.762	1.000	212.0	100.0	1178.6	1642	.0380	26.36
15	0.3	30.533	1.057	.778	1.020	213.1	100.6	1178.9	1610	.0387	25.85
16	1.3	32.568	1.124	.829	1.088	216.3	102.4	1179.9	1515	.0411	24.32
17	2.3	34.604	1.195	.880	1.156	219.6	104.2	1180.9	1431	.0435	22.96
18	3.3	36.639	1.265	.932	1.224	222.7	105.9	1181.8	1357	.0459	21.78
19	4.3	38.675	1.336	.984	1.292	225.6	107.6	1183.1	1290	.0483	20.70
20	5.3	40.710	1.405	1.037	1.360	228.5	109.2	1183.5	1229	.0507	19.72
21	6 3	42.746	1.475	1.089	1.428	231 2	110.7	1184.3	1174	.0531	18.84
22	7.3	44.781	1.545	1.140	1.496	233.8	112.1	1185.0	1123	.0555	18.03
23	8.3	46.817	1.615	1.192	1.564	236.3	113.5	1185.7	1075	.0580	17.26
24	9.3	48.852	1.687	1.244	1.632	238.7	114.8	1186.5	1036	.0601	16.64
25	10.3	50.888	1.758	1.296	1.700	241.0	116.1	1187.2	996	.0625	15.99
26	11.3	52.923	1.828	1.348	1.768	243.3	117.4	1187.9	958	.0650	15.38
27	12.3	54.959	1.898	1.400	1.836	245.5	118.6	1188.5	926	.0673	14.86
28	13.3	56.994	1.969	1.452	1.904	247.6	119.8	1189.1	895	.0696	14.37
29	14.3	59.030	2.039	1.503	1.972	249.6	120.9	1189.7	866	.0719	13.90
30	15.3	61.065	2.108	1.555	2.040	251.6	122.0	1190.3	838	.0743	13.46
35	20.3	71.243	2.459	1.814	2.380	260.9	127.2	1193.0	726	.0858	11.65
40	25.3	81.420	2.811	2.074	2.720	269.1	131.7	1195.4	640	.0974	10.27
45	30.3	91.598	3.162	2.333	3.060	276.4	135.8	1197.6	572	.1089	9.18
50	35.3	101.776	3.514	2.592	3.400	283.2	139.6	1199.6	518	.1202	8.31
55	40.3	111.953	3.865	2.852	3.740	289.3	142.9	1201.5	474	.1314	7.61
60	45.3	122.131	4.217	3.111	4.080	295.6	146.4	1203.2	437	.1425	7.01
65	50.3	132.308	4.638	3.370	4.420	301.3	149.6	1204.8	405	.1538	6.49
70	55.3	142.486	4.919	3.629	4.760	306.4	152.4	1206.3	378	.1648	6.07
75	60.3	152.663	5.270	3.889	5.100	311.2	155.1	1207.8	353	.1759	5.68
80	65.3	162.841	5.622	4.148	5.440	315.8	157.7	1209.1	333	.1869	5.35
85	70 3	173.018	5.973	4.407	5.780	320.1	160.1	1210.4	314	.1980	5.05
90	75.3	183.196	6.325	4.666	6.120	324.3	162.4	1211.6	298	.2089	4.79
95	80.3	193.373	6.676	4.926	6.460	328.2	164.8	1212.8	283	.2198	4.55
100	85.3	203.551	7.027	5.185	6.800	332.0	166.7	1213.9	270	.2307	4.33
110	95.3	223.906	7.730	5.703	7.480	339.2	170.7	1216.0	247	.2521	3.97
120	105.3	244.261	8.433	6.222	8.160	345.8	174.3	1218.0	227	.2738	3.65
130	115.3	264.616	9.136	6.740	8.840	352.1	177.8	1219.8	211	.2955	3.38
140	125.3	284.971	9.909	7.259	9.520	357.9	181.1	1221.5	197	.3162	3.16
150	135.3	305.327	10.54	7.778	10 20	363.4	184.1	1223.2	184	.3377	2.96
160	145.3	325.682	11.24	8.296	10.88	368.7	187.1	1224.8	174	.3590	2.79
170	155.3	346.037	11.95	8.814	11.56	373.6	189.8	1225.1	164	.3798	2.63
180	165.3	366.392	12.65	9.333	12.24	378.4	192.4	1227.7	155	.4009	2 49
190	175.3	386.747	13.35	9.851	12.92	382.9	194.9	1229.1	148	.4232	2.37
200	185.3	407.102	14.06	10.37	13.60	387.3	197.4	1230.3	141	.4431	2.26
250	235.3	508.878	17.57	12.70	17.00	401.1	204.8	1232.3	114	.5464	1.83
300	285 3	610.653	21.08	15.55	20.40	417.5	213.9	1237.1	96	.6486	1.54
350	335.3	712.429	24.59	18.14	23.80	430.1	220.9	1240.8	88	.7498	1.33
400	385.3	814.204	28.11	20.74	27.20	444.9	229.1	1245.1	73	.8502	1.18
450	435.3	915.980	31.62	23.33	30.60	456.7	235.7	1248.6	66	.9499	1.05
500	485.3	1017.75	35.14	25.92	34.00	467.5	241.7	1251.7	59	1.0490	.95
600	585.3	1221.30	42.16	31.11	40.80	487.0	252.5	1257.4	50	1.2450	.80
700	685.3	1424.86	49.20	36.29	47.60	504.1	262.0	1262.4	43	1.4395	.69
800	785.3	1628.41	56.22	41.38	54.40	519.5	270.5	1266.9	38	1.6322	.61
900	885.3	1831.96	63.25	46.56	61.20	533.6	278.4	1271.0	34	1.8235	.55
1000	985.3	2035.51	70.20	51.85	68.00	546.5	285.3	1274.8	31	2.0140	.50

TO FIND THE ELASTIC FORCE OF STEAM.

F = Force in inches of mercury.
T = Temperature of the steam in degrees Fahrenheit.
C = 177 for fresh water.
177.6 for sea water.
185.6 for water saturated with salt.

$$F = \left(\frac{T + 100}{C}\right)^6.$$

TABLE OF STEAM USED EXPANSIVELY.

Initial pressure in lbs. per square inch.	Average Pressure of Steam in lbs. per square inch throughout the Stroke. — Portion of Stroke at which Steam is cut off.					
	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$
5	4.8	4.6	4.2	3.7	2.9	1.9
10	9.6	9.1	8.4	7.4	5.9	3.8
15	14.4	13.7	12.7	11.1	8.9	5.7
20	19.2	18.3	16.9	14.8	11.9	7.6
25	24.1	22.9	21.1	18.5	14.9	9.5
30	28.9	27.5	25.4	22.2	17.9	11.5
35	33.8	32.1	29.6	25.9	20.8	13.4
40	38.5	36.7	33.8	29.6	23.8	15.4
45	43.4	41.3	38.1	33.3	26.8	17.3
50	48.2	45.9	42.3	37.0	29.8	19.2
60	57.8	55.1	50.7	44.5	35.7	23.1
70	67.4	64.3	59.2	52.4	41.7	26.9
80	77.1	73.5	67.7	59.3	47.7	30.8
90	86.7	82.6	76.1	66.7	53.6	34.6
100	96.3	91.8	84.6	74.1	59.6	38.4
110	106.0	101.0	93.1	81.5	65.6	42.5
120	115.2	110.2	101.5	89.4	71.5	46.1
130	125.4	119.1	110.0	95.3	77.5	50.0
140	134.9	128.6	118.5	103.8	83.3	53.8
150	144.7	137.8	126.4	111.2	89.4	57.7
160	153.6	147.0	135.4	118.2	95.4	61.5
180	173.5	164.6	152.3	132.9	107.3	69.2
200	192.7	183.7	169.3	148.3	119.3	76.9

To find the pressure at the end, or at any point of the stroke, in the cylinder of an expansive engine.

P = Initial pressure of steam, in lbs. per square inch.
D = Distance travelled by piston before steam is cut off.
L = Distance travelled by the piston when the pressure of the steam = A.
A = Pressure of steam in the cylinder when piston has travelled a distance = L.

$$\text{Then } A = \frac{P\,D}{L} \text{ and } L = \frac{P\,D}{A}.$$

The formula used to find the numbers in the Table above is as follows:—

L = Length of the strok e, in inches.
D = Distance the piston has travelled when steam is cut off, in inches.

R = Ratio of expansion $= \frac{L}{D}$.

H = Hyperbolic logar ithm of R (see Table below).
P = Initial pressure of steam, in lbs. per square inch.
M = Mean pressure during whole of stroke, in lbs. per square inch.

$$M = \frac{P\,(H+1)}{R}.$$

L	R	H	L	R	H
$\frac{1}{10}$	10	2.302	$\frac{6}{10}$	1.66	.507
$\frac{1}{8}$	8	2.079	$\frac{5}{8}$	1.60	.470
$\frac{2}{10}$	5	1.609	$\frac{7}{10}$	1.42	.351
$\frac{1}{4}$	4	1.386	$\frac{3}{4}$	1.33	.285
$\frac{3}{10}$	3.33	1.203	$\frac{8}{10}$	1.25	.223
$\frac{3}{8}$	2.66	.978	$\frac{7}{8}$	1.14	.131
$\frac{4}{10}$	2.5	.916	$\frac{9}{10}$	1.11	.104
$\frac{1}{2}$	2	.693			

1 atmosphere equals 14.71 lbs. per square inch, or 15 lbs. approximately.
" " 29.92 inches of mercury, or 33.9 feet of water.

An approximate rule for finding the nominal horse-power of a single-cylinder engine is: square the diameter of cylinder in inches and divide the product by ten.

COMPARATIVE EVAPORATIVE VALUE OF FUELS.

The feed water being 212° Fahrenheit when it enters the boiler, the following results were obtained from the consumption of 1 lb. of the undermentioned fuels. The first eight give the average of many samples tested by Messrs. Delabèche and Playfair.

	Specific Gravity.	lbs. of water evaporated.	Comparative values.
Welsh coal	1.315	9.05	1.000
Newcastle coal	1.256	8.01	0.885
Derby and York coal	1.292	7.58	0.837
Lancashire coal	1.273	7.94 By trial.	0.877
Scotch coal	1.260	7.70	0.851
British average	1.290	8.13	0.898
Irish Anthracite	1.590	9.85	1.088
Patent fuels	1.167	9.20	1.016
French coal (average)	1.310	8.00	0.884
Lignites (average)	1.198	6.66	0.736
Well dried peat	1.300	4.52 Approx.	0.500
Coke (average)	0.750	9.00	0.995
Oak	0.930	4.52	0.500
Pine	0.660	2.5	0.276

WATER POWER. USEFUL MEMORANDA RELATING TO HYDRAULICS.

1 cubic foot of fresh water weighs 62.425 lbs. = 557 cwt., or .028 ton.
1 cubic foot of sea water weighs 64.11 lbs. = 572 cwt., or .0286 ton.
1 cubic inch of fresh water weighs .03612 lb.
1 gallon of fresh water weighs 10 lbs.
1 gallon of water contains 277.27 cubic inches.
1 cubic foot of water contains 6.24 gallons.
1 ton of water contains 35.9 cubic feet (approximately 1 cubie metre).

1 foot in head gives a pressure of .4335 lb. per square inch.
Inches of rainfall × 2323200 give cubic feet per square mile.
Inches of rainfall × 14500000 give gallons per square mile.
Inches of rainfall × 3630 give cube feet per acre.
1 inch of rainfall is approximately 100 tons per acre.

TABLE OF THEORETICAL VELOCITY AND PRESSURES DUE TO VARIOUS HEADS.

Head in feet.	Velocity in feet per sec.	Velocity in feet per min.	Pressure in lbs. per sq. in.	Pressure in cwt. per sq. ft.	Head in feet.	Velocity in feet per sec.	Velocity in feet per min.	Pressure in lbs. per sq. in	Pressure in cwt. per sq. ft.
1	8.	482	.43	.55	35	47	2851	15.1	19.5
2	11.3	681	.87	1.11	40	51	3048	17.3	22.3
3	13.9	835	1.3	1.67	50	57	3408	21.7	27.8
4	16.	964	1.73	2.23	60	62	3733	26	33.4
5	18.	1078	2.17	2.78	70	67	4032	30.3	39
6	19.7	1180	2.6	3.34	80	72	4311	34.7	44.5
8	23.	1363	3.47	4.45	90	76	4573	39	50.1
10	25.	1524	4.33	5.57	100	80	4820	43.3	55.7
12	28.	1669	5.2	6.68	125	90	5389	54	69.6
15	31.	1866	6.5	8.36	150	98	5903	65	83.6
18	34.	2045	7.8	10.03	175	106	6466	76	97.5
20	36.	2155	8.7	11.14	200	113	6816	87	111
25	40.	2410	10.8	13.93	250	127	7621	108	139
30	44.	2640	13.	16.71	300	139	8348	130	167

To find the numbers in the above Table for heads not given.

V = Velocity in feet per second (theoretical). | H = Head of water.
T = Velocity in feet per minute (theoretical). | P = Pressure in lbs. per square inch.

$P = H \times .4335 \quad V = 8.025\sqrt{H} \quad T = 482\sqrt{H}.$

$H = .0155\,V^2 \quad H = P \times 2.307.$

Pressure in lbs. per square foot $= H \times 62.4$.

WATER POWER, &c.—*Continued.*

As it is frequently necessary to ascertain the quantity of water available for driving a water wheel or turbine, the following rules for gauging water flowing over a sill, &c., may be found useful.

FORMULA FOR GAUGING WATER FLOWING OVER A SILL.

H = Height of surface of water above sill, in feet.
I = Ditto if measured, in inches.
V = Velocity of water approaching sill, in feet per second.
C = Cubic feet discharged over a sill 1 foot wide per minute.

$C = 214\sqrt{H^3}$ or $5 \cdot 15\sqrt{I^3}$ if the stream above the sill is motionless.

$C = 214\sqrt{H^3 + \cdot 035\ V^2 H^2}$ if the stream above the sill is in motion.

In gauging, the waste-board must have a thin edge. The height must be measured from the top of the sill to the level of the water surface some distance back from the waste-board where it is not affected by the fall.

HAWKSLEY'S FORMULA FOR THE DELIVERY OF WATER IN PIPES.

G = Number of gallons delivered per hour.
L = Length of pipe, in yards.
H = Head of water, in feet.
D = diameter of pipe, in inches.

$$D = \tfrac{1}{15}\sqrt[5]{\frac{G^2 L}{H}} \qquad G = \sqrt{\frac{(15\ D)^5\ H}{L}}.$$

WEISBACH'S FORMULA FOR THE FRICTION OF WATER IN PIPES.

H = Head to overcome friction, in feet.
L = Length of pipe, in feet.
D = Internal diameter of pipe, in feet.
V = Velocity of water, in feet per second.

$$H = \left\{ 0.0144 \times \frac{0.01716}{\sqrt{V}} \right\} \frac{L}{D} \times \frac{V^2}{64.4}.$$

WATER WHEELS AND TURBINES.

The maximum theoretical efficiency for undershot water wheels is obtained when the speed of the periphery is half the speed of the driving stream; but experience has shown that the most suitable speed for paddle-wheels in an open current is 40 per cent. of the speed of the stream. The efficiency of undershot wheels is seldom more than 27 to 30 per cent. of the power expended, but in Poncelot's undershot wheel it reaches 50, 55, and even 60 per cent.

Breast wheels give an efficiency of about 75 per cent. of power expended with a velocity of 5 feet per second at the periphery, but in an exceptional case as much as 93 per cent. was registered by M. Morin. The usual velocity for breast wheels is about 6 feet per second at the periphery; minimum 3 ft. 6 in., maximum 7 feet. Overshot wheels answer well for falls of from 13 to 20 feet, and give an efficiency of 70 to 75 per cent.

The power of any of the above forms of wheels may be obtained by multiplying the weight of the water used, by the height it falls through and the factor of efficiency given.

In Fourneyron's turbine the factor of efficiency varies from .79 to .24 according to the state of the regulating sluices, from which it is evident that they are far more economical when working at full power.

For outward-flow turbines, it has been found by experience that the height of the orifices at the circumference of the wheel should be one-tenth the diameter of the wheel; that the sum of the shortest distances between the buckets should equal the diameter of the wheel; that the width of the crowns should be four times the shortest distance between the buckets; and that the sum of the shortest distances between the curved guides taken near the wheel, should be equal to the interior diameter of the wheel. For any fall greater than 40 feet the first rule should be modified, the height of orifices decreasing as the fall increases. By attention to these points an efficiency of 75 per cent. may be realized. In turbines with a downward flow, such as Fontaine's, an efficiency of 70 per cent. may be reached when working at full power The best speed for the periphery of these wheels is 55 per cent. of the theoretical velocity due to the head.

Jonval's turbines give an efficiency of 72 per cent. under full work, and the best velocity for the exterior of the wheel is 70 per cent. of that due to the head

The inward flow, or Thompson's vortex turbine, has realized an efficiency of 77½ per cent. or even more; the speed of periphery in this class of turbine should be half of that due to the head.

It is stated that the Girard turbine at the Paris Waterwork has reached an efficiency of 87 per cent.